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SUMMARY REPORT
ON TASK 2

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THE EMITTANCE OF CALORIMETER DISCS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
(Contract NAS8-5196)

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SOUTHERN RESEARCH INSTITUTE
2000 9th Avenue S. Birmingham 5, Alabama

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SUMMARY

This is a final report covering the work performed under Task Order No. 2 of Contract No. NAS8-5196 from April 1 to June 1, 1963. This contract involves research, development, and prototype model construction of calorimeter and thermocouple assemblies designed toward the Saturn and C-1 environment.

The work performed under this task order was concerned with the emittance of calorimeter sensing discs and the temperature cycling effects in air on special coatings.

The specimens evaluated were $\frac{1}{2}$" diameter discs with a copper substrate and smooth and grooved surfaces coated with Chrycote or platinum black. Specimen temperatures were monitored during the evaluations by attaching thermocouples to the back surface of the specimens.

The emittance of the grooved specimens was consistently higher than the emittance for the smooth ones with the same exposure history. Also, there was less data scatter for the grooved specimens within any single run and less deviation for successive runs on the same specimen. The emittance versus temperature curve for the grooved specimen within the same exposure history generally was more linear, undoubtedly influencing the observation of less scatter within a run and less deviation between runs.

The emittance of the grooved specimens in the vicinity of 750° F was altered somewhat (± 0.1) by prior exposures to about 900° F. Above 750° F, the emittance was changed only slightly by previous exposures in the range of 700 to 1400° F. For the smooth specimens, prior runs altered the emittance considerably over the full temperature range. The platinum black coating seemed to provide the most reproducible emittance for both the smooth and grooved surfaces.

The coatings on the smooth surfaces seemed to degrade less with the temperature exposures; apparently, the cavity effect of the grooves, and not the coatings, provided the stability in the emittance. The Chrycote appeared

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to be the most stable coating on the smooth finish; however, both flaked and there was no great difference in coating loss during exposures.

There was rather good agreement in the emittance values for all of the grooved specimens on the first run on each. This disc should provide a reasonably predictable calorimeter sensing device.

AUTHOR

SCOPE

The scope of this program was to determine the emittance and variation of emittance with temperature and temperature cycling of radiation slug calorimeters.

The work program formulated was: (a) to determine the room temperature reflectance of duplicate specimens of each surface and coating in order to calculate the emittance at this temperature; (b) to determine the emittance and change in emittance of the same specimens as a result of cycling the temperature from 500° F to 1472° F (260° C to 800° C) in air; (c) to determine the emittance and change in emittance of one specimen of each surface and coating resulting from exposure to a temperature approximately 100° F below the softening point of copper (approximately 1850° F or 1010° C); and (d) to determine the maximum temperature during a single run in which the emittance of the sensing discs would remain in calibration for subsequent use.

All evaluations were made in simulated conditions with a dry air atmosphere. The specimen temperature was monitored by thermocouples welded to the bottom face.

SPECIMENS

The specimens were copper discs $\frac{1}{2}$" in diameter and $\frac{1}{8}$" thick, with a smooth or a spirally grooved surface (42 grooves/in., 0.015" width x 35°) coated with either a Chrycote or platinum black coating. Eighteen specimens were supplied by NASA; nine specimens were coated with the platinum black and nine with the Chrycote. Of the nine specimens of each coating, three had smooth surfaces and six had grooved surfaces. Several flat, bare copper specimens were made here to provide some preliminary information on the substrate material, the way it oxidized in air, and the method of attaching the thermocouples.

Runs were made on all specimens with the surfaces in the "as-received" condition. The coatings and grooves on the specimens were not absolutely smooth nor uniform. Extreme care was exercised in attaching thermocouples to the rear of the specimens to prevent alteration of the specimen surfaces.

For ease of identification, the specimens were designated with three characters: the first, "C" or "P" indicating the coating on the specimen; the second, a numeral from 1 to 9; and third, "G" or "S" indicating a grooved or smooth surface. Thus, specimen "P-2G" was grooved, No. 2 in the series, and had a platinum black coating.

APPARATUS AND PROCEDURE

The reflectance at room temperature was determined by a direct measurement technique that compared the energy reflected by the specimen to that reflected by a front surface mirror when using a 1500° F Globar as a source. A description of the apparatus is included in the Appendix. This apparatus was designed to evaluate a specimen 2" x 2", which made slight modifications necessary. The smaller specimens for this program were glued flush on flat-surface holder boards to insure that the specimens were held in a normal plane when placed in the apparatus. Black velvet cloth was used to shield all extraneous portions of the apparatus from view by the radiometer.

The total normal emittance was determined by comparing the energy received by a radiometer from the sample to that received from a blackbody cavity maintained at the same temperature. A complete description of the apparatus and procedure is included in the Appendix.

In order to simulate conditions existing in the calorimeter in the space vehicle, a dry air atmosphere was utilized. Temperature measurements were made with a chromel-alumel thermocouple welded to the back side of the specimen. Optical pyrometer readings on the specimen surface were obtained to confirm the temperatures indicated by the thermocouples.

DATA AND RESULTS

Reflectance of Smooth and Grooved Coated, Chrycote and Platinum Black Specimens at 75° F

Two specimens of each surface and coating were evaluated for reflectance, in duplicate, with the results as follows (see Tables 1-8):

	Reflectance	
Coating	Grooved Surface	Smooth Surface
Chrycote	0.20 - 0.23	0.40 - 0.45
Platinum black	0.11 - 0.14	0.13 - 0.16

These values are within an estimated accuracy of 10% and were in rather good agreement with the extrapolation of the emittance data obtained at higher temperatures as discussed later.

Emittance of Bare, Smooth Copper Substrate

Prior to evaluating the emittance of the coated specimens, some bare copper slugs were evaluated with successive runs in air with thermocouples attached by welding and peening to establish the emittance of the substrate, to observe the oxidation of the bare copper with its influence on emittance, and to confirm that comparable data would be obtained with both methods of thermocouple attachment. Welding is the best method; however peened thermocouples become necessary when the surface will not accept or retain welded ones. Since calculations showed that the temperature drop through the thickness of the specimens was less than 3° F, the thermocouples were attached to the back side out of view of the radiometer.

The flat bare copper began to oxidize heavily in air between 800° F and 1000° F with a considerable increase in the emittance, see Figure 1. After the copper slugs were thoroughly oxidized, the emittance data were considerably higher up to the maximum temperature of the first exposure. On the first exposure, the emittances of the different specimens were similar, but not in precise agreement (see Figure 2); whereas, for the second exposures, the emittances of the different specimens were in close agreement; above about 1650° F, the emittance decreased rather sharply, see Figure 3.

A flat bare copper specimen was run in dry argon and then in dry air to establish the absolute values in argon and the influence of the prior run in argon on a subsequent run in air, see Figure 4. In argon, the emittance remained relatively low to about 1600° F. On the subsequent run in air, the emittance was similar to that of the first runs in air for the prior specimens; see Figure 2.

Emittance of Coated Specimens Exposed to 1472° F

General

After the preliminary runs on the bare copper, the runs were made on the smooth and grooved specimens coated with Chrycote and platinum black. In evaluating the emittance and change in emittance to approximately 800° C (1472° F), three cycles were made using duplicate specimens of each coating and surface. Data obtained are shown in Figures 5-8 and Tables 9-16, with the successive runs for each specimen shown on the respective figures.

Emittance of Grooved Chrycote Specimens

Figures 9-11 are comparisons of the emittances during the first, second, and third cycles for the two grooved copper specimens with the Chrycote coating. The emittances of the two specimens were almost equal over the temperature range during the second and third cycles for each; whereas, the emittances of the specimens were somewhat different during the first cycle for each. A comparison of two grooved specimens with the Chrycote coating is shown in the picture in Figure 12. Observe the flaking of the surface.

Emittance of Smooth Chrycote Specimens

Figures 13-15 are comparisons of the emittances of specimens C-7S and C-8S (smooth, Chrycote) during each of the three cycles. There was no noticeable difference in the emittances of the two specimens during the first run for each. There was a definite difference in the emittances of the two specimens during the second run for each, probably as a result of the relative amount of flaking and cracking of the Chrycote coating. During the third cycle, the emittances of the two specimens deviated by a near constant amount of 0.05 over the temperature range. Figure 16 is a photograph of the two smooth specimens with the Chrycote coating. One specimen had not been exposed to temperature cycling and the other had been cycled to approximately 800° C (1472° F) three times.

Emittance of Grooved, Platinum Black Coated Specimens

Figures 17-19 are comparisons of the emittances of the two grooved, platinum coated specimens during each of the three temperature cycles. The emittances of the specimens were about equal over the temperature range during the first cycle. The emittance of specimen P-1G (platinum, grooved) rose noticeably during the second cycle and remained above the emittance of specimen P-2G through the third cycle.

Emittance of Smooth, Platinum Black Coated Specimens

Figures 20 and 21 are comparisons of the emittances of the two smooth copper specimens with platinum black coating for each of the different cycles. The emittances of the two specimens were very similar and almost equal during the first cycle. During the second cycle for each specimen, the emittances deviated slightly over the temperature range, but were in fair agreement.

The emittances of the smooth copper specimens with the platinum black coating varied considerably with the various temperature cyclings. The emittance of specimen P-7S was approximately 40% higher during the second cycle in the range of 500° F to 1000° F; during the third cycle, the emittance of the specimen dropped well below the original values. Before beginning the third cycle, almost 70% of the platinum coating had flaked off of the surface. The emittance of specimen P-8S changed from a positive sloping curve over the temperature range to a concave curve during the second cycle. At the completion of the second cycle, all of the platinum coating had flaked off of the surface. Figure 22 is a picture comparing the surfaces of two smooth specimens with platinum coating; one specimen was unexposed to temperature cycling and the other had been cycled to approximately 800° C three times.

The platinum black coating on the smooth copper specimens was very sensitive to mechanical shock or vibration after one exposure to approximately 800° C (1472° F). The emittance apparatus was opened at the completion of various cycles to inspect the specimens. Very often, a slight jar during this procedure would cause the platinum coating to begin "popping off" the surface. This reaction usually continued without further agitation until the specimen was void of all its coating.

Emittance of Specimens Exposed to Near Melting

General

In cycling the specimens to 100° F below the softening point of copper, it was found that the welded thermocouple connections tended to fail due to the heavy oxidation of the copper substrate. As a result, most of the thermocouples were peened in place.

One specimen of each coating and surface was cycled twice to approximately 1850° F (1010° C). Figures 23-26 (Tables 17-20) show the effect of cycling the various specimens to the temperature near melting.

Emittance of Grooved Chrycote Specimens

The emittance of the grooved specimen with the Chrycote coating dropped slightly after the first cycle, see Figure 23. The thermocouples were welded to the specimen during the first cycle, but failed and were attached by peening for the second exposure. A photograph comparing the three grooved specimens with the Chrycote coating—representing the different top exposure temperatures of this program—is shown in Figure 27. After having been exposed to approximately 1850° F, the peaks of the grooves lost all coating and were rounded.

Emittance of Smooth Chrycote Specimens

The emittance of the smooth copper specimen with Chrycote coating rose very noticeably after the first cycle to approximately 1850° F, see Figure 24. The emittance during the first exposure was slightly below that of the other two similar specimens exposed to about 1472° F. During the first exposure the thermocouple was attached to the specimen by welding; whereas, during the second exposure the thermocouple was peened into the surface. The emittance of this specimen during the second exposure was almost constant throughout the temperature range (Figure 24), and was slightly higher than the emittances of the other two similar specimens exposed to 1472° F. After exposure to approximately 1850° F, the smooth

Chrycote specimen appeared very similar to the specimens that had been exposed to 1472° F during the three cycles.

Emittance of Grooved, Platinum Black Specimens

The emittance of specimen P-3G (grooved plus platinum black) was almost equal to the emittances of the other two similar specimens exposed to 1472° F over the temperature range; see Figure 25 for the data. During the second exposure, the emittance was slightly higher than for the two previous similar specimens exposed to 1472° F. A photograph comparing three grooved copper specimens with the platinum black coating after different exposures is shown in Figure 28. The rounding of the peaks on the grooves was also characteristic of the platinum black coated specimens after exposure to approximately 1850° F (1010° C). During both cycles, the thermocouple was peened in place.

Emittance of Smooth, Platinum Black Specimens

The emittance of specimen P-9S (smooth surface with platinum black coating) was in close agreement with the emittances of the two specimens exposed to 1472° F during the first cycle. During the second exposure to approximately 1850° F, the emittance of specimen P-9S was much lower than the emittances of the two previous specimens exposed to 1472° F. Upon inspection after the second exposure, it was found that the entire platinum coating had remained intact even though the specimen had begun to melt. Upon removing the specimen from the apparatus, the coating was knocked from the specimen. The thermocouple was attached to this specimen during both cycles by peening and failed before the completion of the second cycle.

Influence of Prior Exposure Temperature on Emittance of Grooved Specimens

In an attempt to determine the temperature to which a specimen could be cycled without affecting its subsequent emittance, one grooved specimen of each coating was cycled to approximately 900° F, 1200° F, and 1600° F; see Figures 29 and 30 and Tables 21 and 22. The emittance of specimen C-4G (grooved, Chrycote) was slightly lower than the emittances of the two specimens exposed to 1472° F. Above 750° F, the deviation of emittance was quite small for the successive runs.

There was a definite rise in the emittance at the lower temperatures of the grooved specimen with the platinum coating (P-4G) after the first cycle to about 900° F. Recall that the emittances of the two similar specimens exposed to 1472° F also rose during the second cycle. The emittance of this specimen was in quite close agreement with the emittances of these other two similar specimens.

Perhaps the calorimeter discs should be heat soaked prior to use to minimize the shift in emittance that occurs at about 750° F after the first cycle. Both coatings provide reasonably stable emittances above 750° F.

Comparison of Emittance of All Coated Specimens on First Exposure

Comparisons of the emittances during the first exposure of each coating and surface are shown in Figures 31-34. The scatter of emittance values in the temperature range from 500° F to 1000° F for the grooved specimens with the Chrycote coating is readily noticeable in Figure 31. For the remaining specimens of each surface and coating, the emittance values were quite similar during the first cycle for each over the entire temperature range, although some additional scatter existed in the vicinity of 750° F. For each type of specimen, the emittance calculated from the room temperature reflectance is shown on the figures and the curve was extrapolated to the data point.

A study of the curves indicates that the emittance of the smooth surface for each coating was lower than for the grooved one up to about 1300° F to 1500° F. Above this temperature, the emittances of both finishes were about equal. Generally, the grooved surfaces provided an emittance about constant with temperature in sharp contrast with the behavior of the smooth ones.

General

The time at each temperature level was not held constant for the different specimens. The degradation of the special coating materials is undoubtedly time dependent and would produce differences in emittances of similar specimens relative to time-temperature exposure. Further, the oxidation of the copper substrate (as the surface flaked) was both a temperature and time function.

There was a noticeable amount of variation in the emittance values of all specimens in the 500° F to 1000° F temperature range that was not experienced at the higher temperature. Perhaps changes in the coatings or in the exposed part of the substrate caused this variation. Several of the runs provided orderly data suggesting that the material—and not entirely experimental scatter—was the cause. The coatings of all of the specimens tended to flake in varying amounts during temperature cycling depending upon the coating and surface of the particular specimen. This flaking action occurred first on the edges of the smooth surface specimens and continued toward the center. On the specimens with the grooved surface, the flaking action seemed to occur relatively uniformly over the entire surface of the specimens appearing initially on the peaks of the grooves. The flaking of the coatings on the grooved specimens was within the field of view of the radiometer immediately after flaking initiated; whereas, the flaking action associated with the smooth specimens was not visible to the radiometer until it had progressed from the edge to a point near the center of the specimens.

CONCLUSIONS

The emittance of the grooved specimens was consistently higher and more linear than for the smooth ones. There was no big difference in the performance of the coatings.

The agreement in emittance values was rather good between specimens with the same exposure history. The grooved specimens provided more constant values for successive runs.

The most predictable emittance was obtained for the grooved and coated specimens on the first exposure for each.

Submitted by:

by C D Pears

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Assistant Engineer
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C. D. Pears, Head
Analysis and Measurements Section

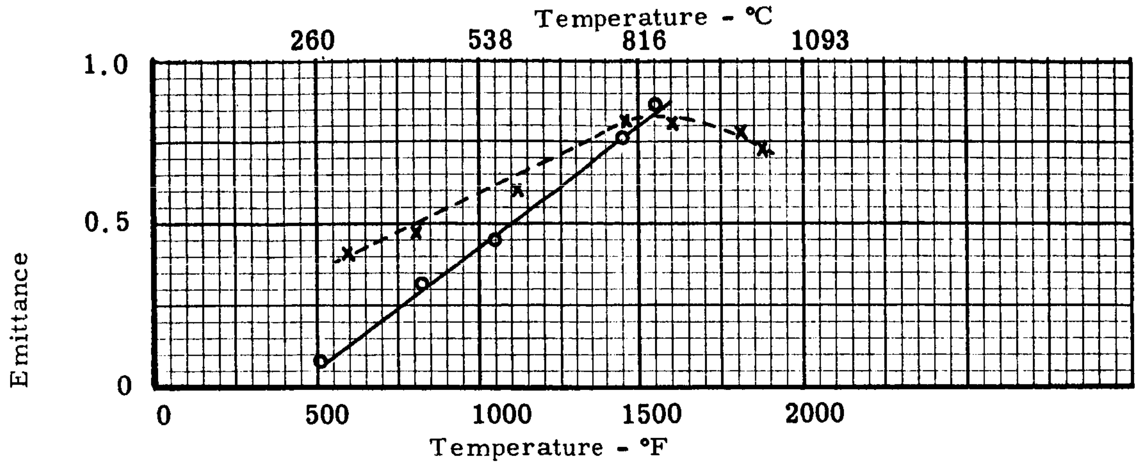
Approved:

S Oglesby Jr

Sabert Oglesby, Jr., Head
Engineering Division

5931-1481-VI
(10:15) gcf am cm mm

Specimen No. 4 - Welded Thermocouple
o - Run No. 1 - Dry Air Atmosphere
x - Run No. 2 - Dry Air Atmosphere



Specimen No. 3 - Peened Thermocouple
o - Run No. 1 - Dry Air Atmosphere
x - Run No. 2 - Dry Air Atmosphere

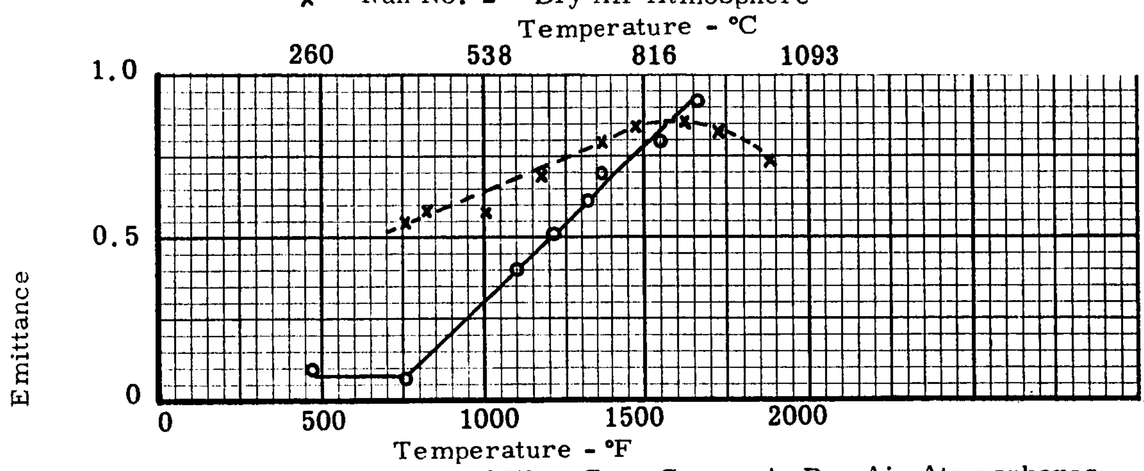


Figure 1. Emittance of Flat, Bare Copper in Dry Air Atmospheres For Successive Runs on Same Specimen

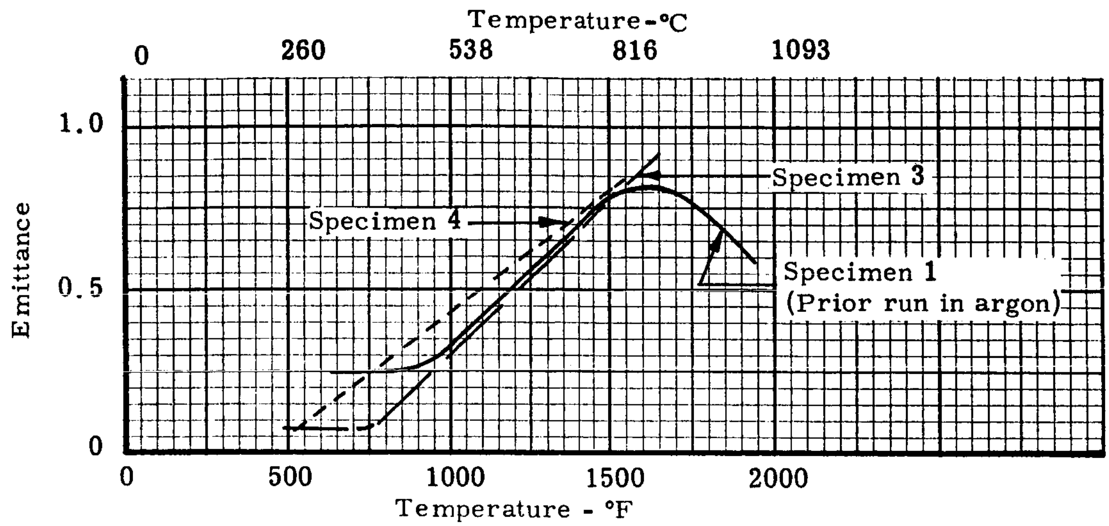


Figure 2. Comparison of the Emittance of the Flat, Bare Copper Specimens During the First Run for Each Specimen

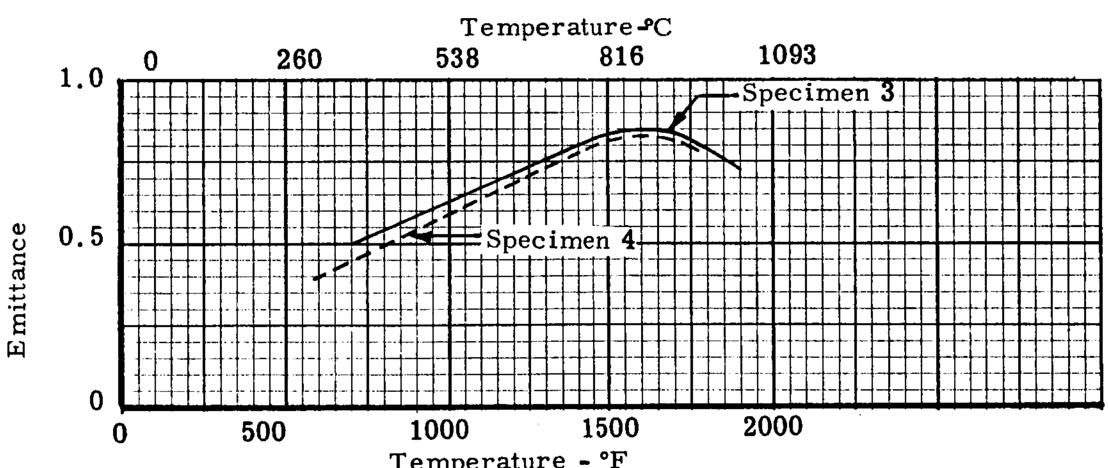


Figure 3. Comparison of the Emittance of the Flat, Bare Copper Specimens During the Second Run for Each Specimen

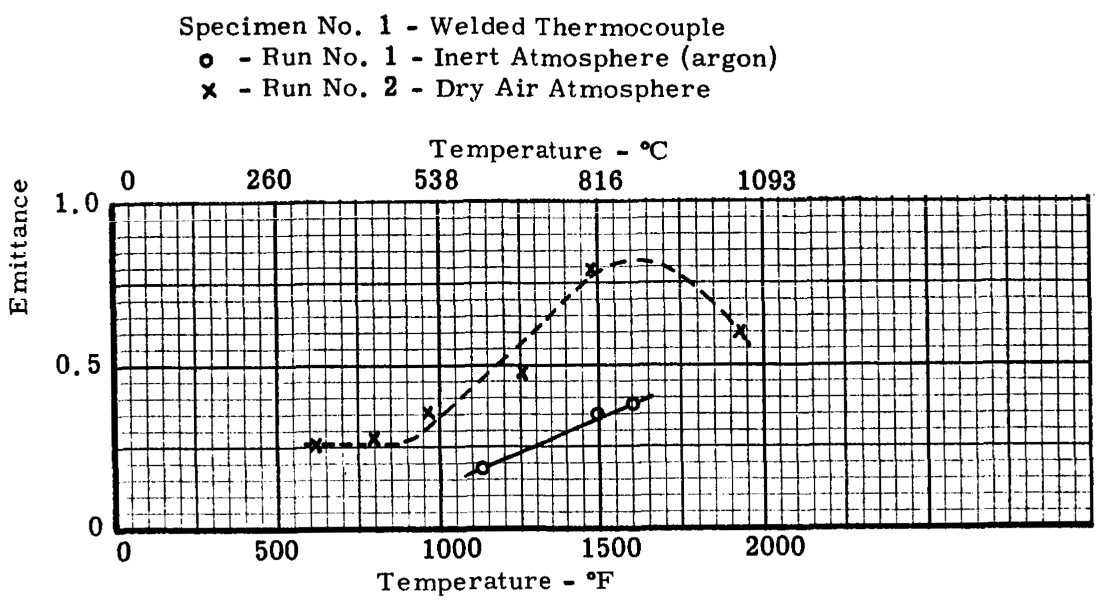
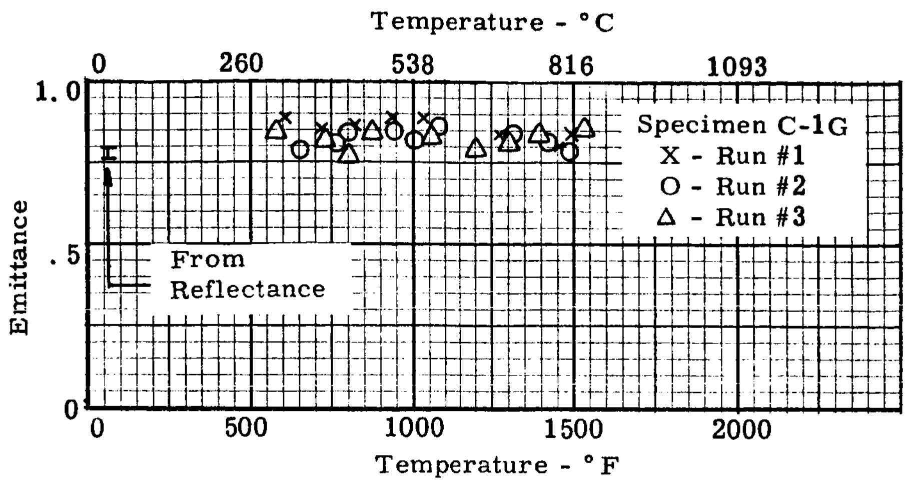


Figure 4. Emittance of Flat Bare Copper in Successive Inert and Dry Air Atmosphere



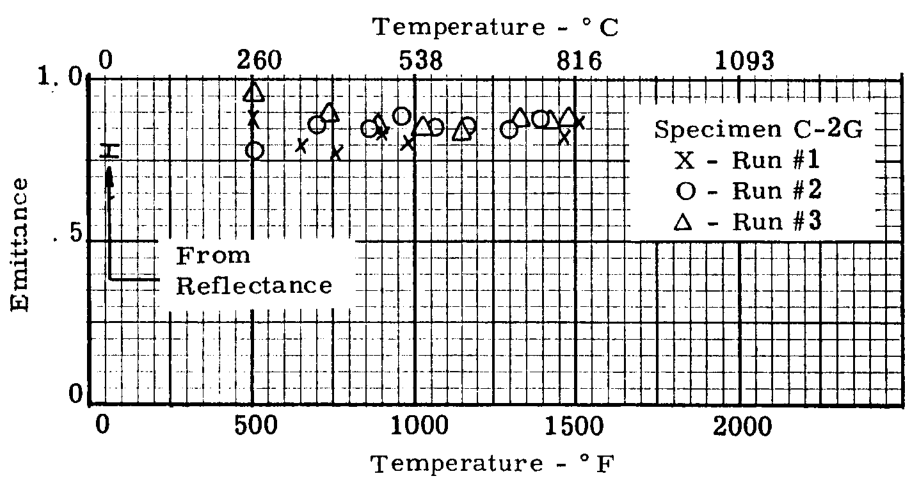
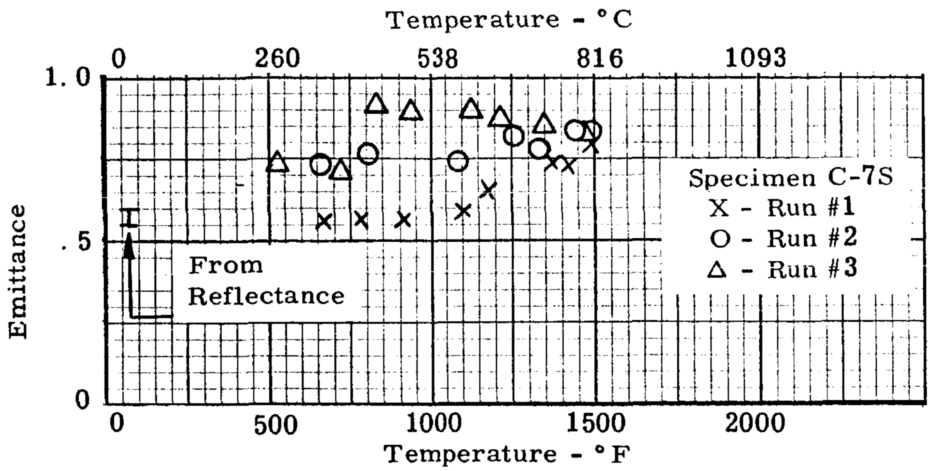


Figure 5. Emittance in Air of Grooved Copper Specimens with Chrycote Coating, for Successive Runs on Same Specimen.



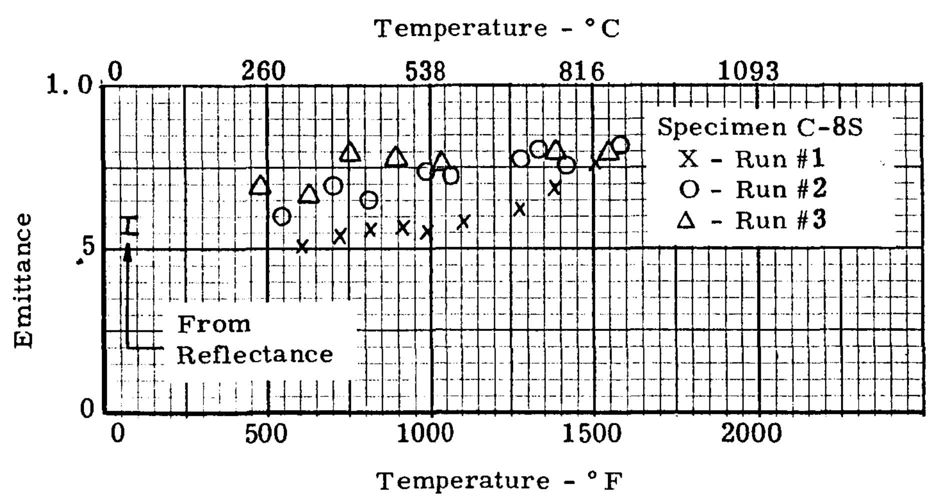
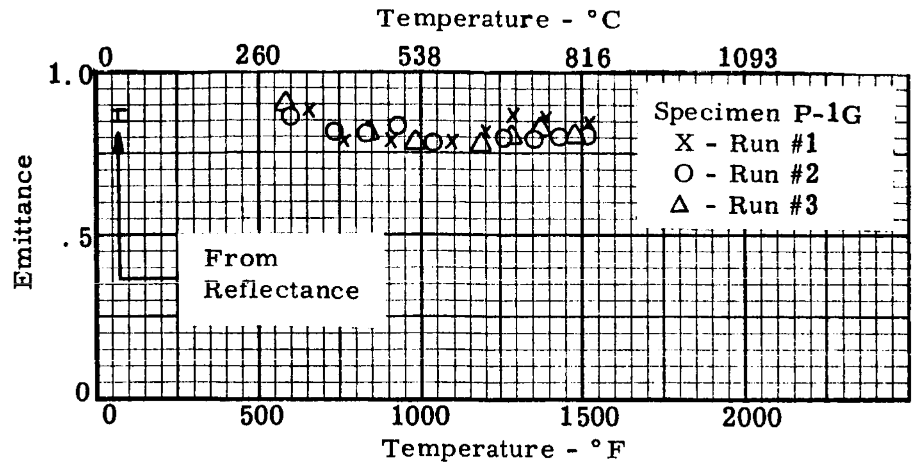


Figure 6. Emittance in Air of Smooth Copper Specimens with Chrycote Coating, for Successive Runs on Same Specimen.



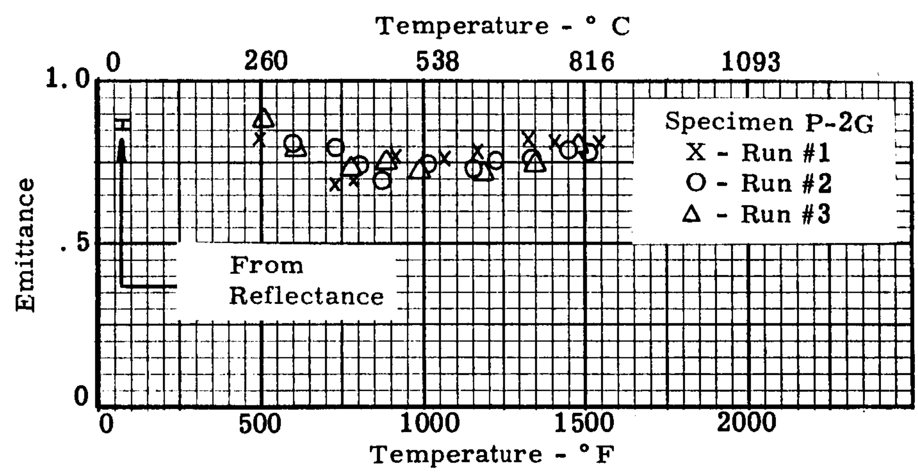
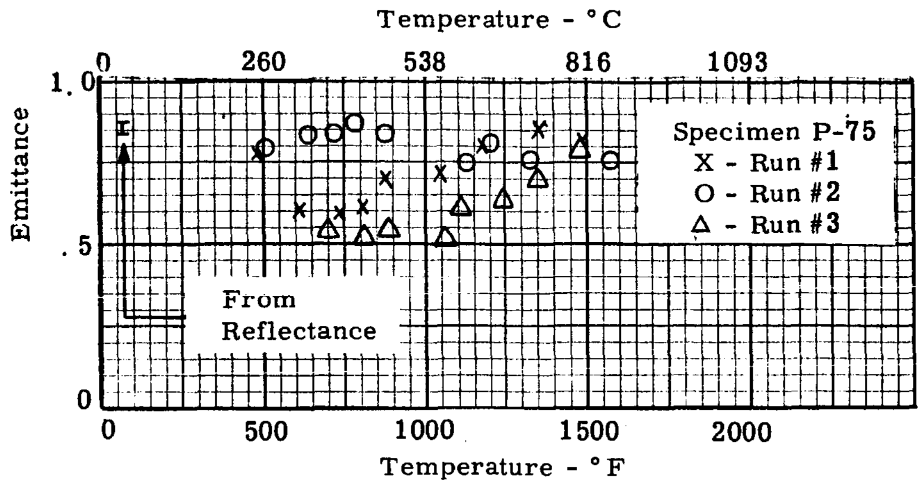


Figure 7. Emittance in Air of Grooved Copper Specimens with Platinum Black Coating,for Successive Runs on Same Specimen.



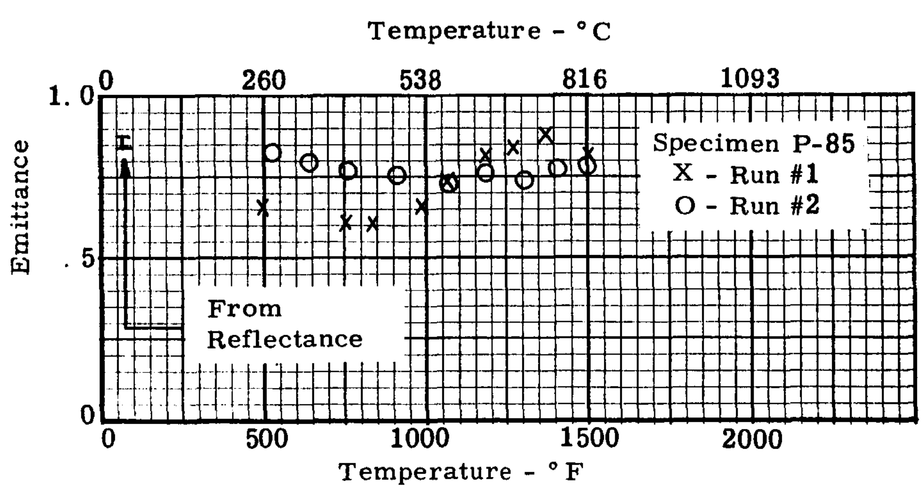


Figure 8. Emittance in Air of Smooth Copper Specimens with Platinum Black Coating, for Successive Runs on Same Specimen.

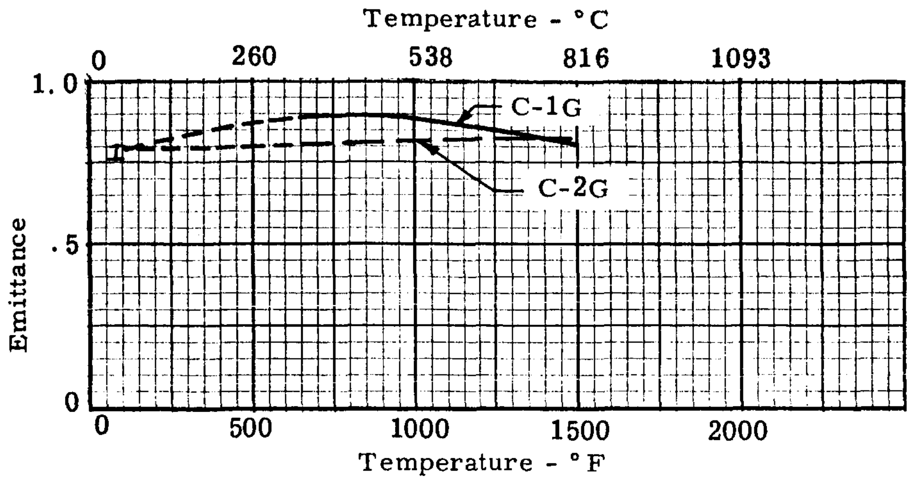


Figure 9. Comparison of Emittance of Grooved Copper Specimens with Chrycote Coating During the First Run for Each Specimen.

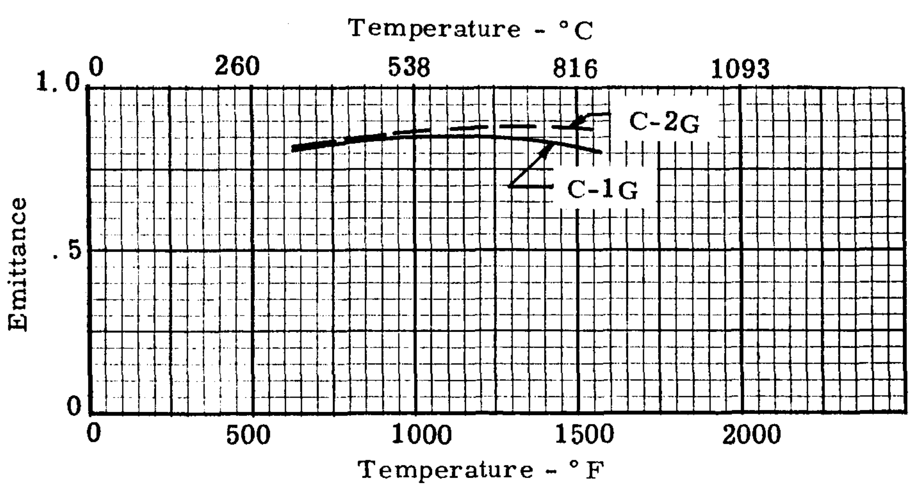


Figure 10. Comparison of Emittance of Grooved Copper Specimens with Chrycote Coating During the Second Run for Each Specimen.

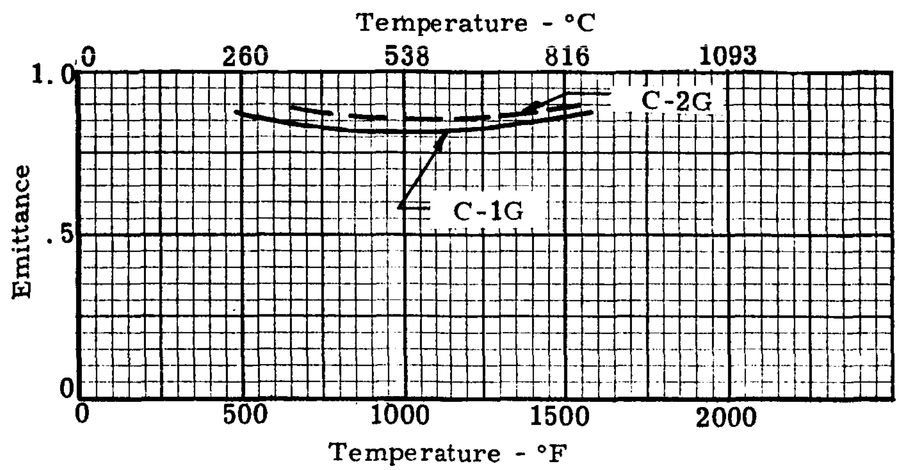


Figure 11. Comparison of Emittance of Grooved Copper Specimens with Chrycote Coating during the Third Run for Each Specimen.

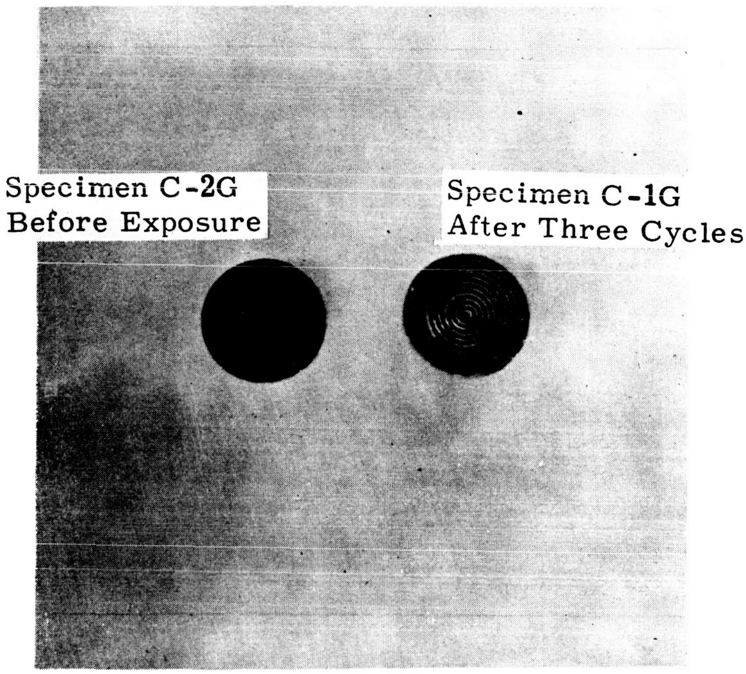


Figure 12. Picture of the Grooved Copper Specimen With the Chrycote Coating Before and After Exposure in Air to About 1472°F (800°C)

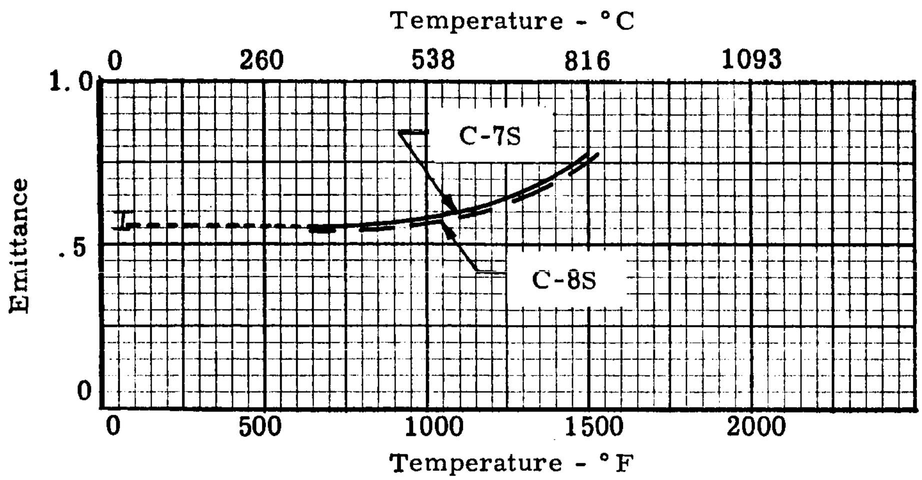


Figure 13. Comparison of Emittance of Smooth Copper Specimens with Chrycote Coating During the First Run for Each Specimen.

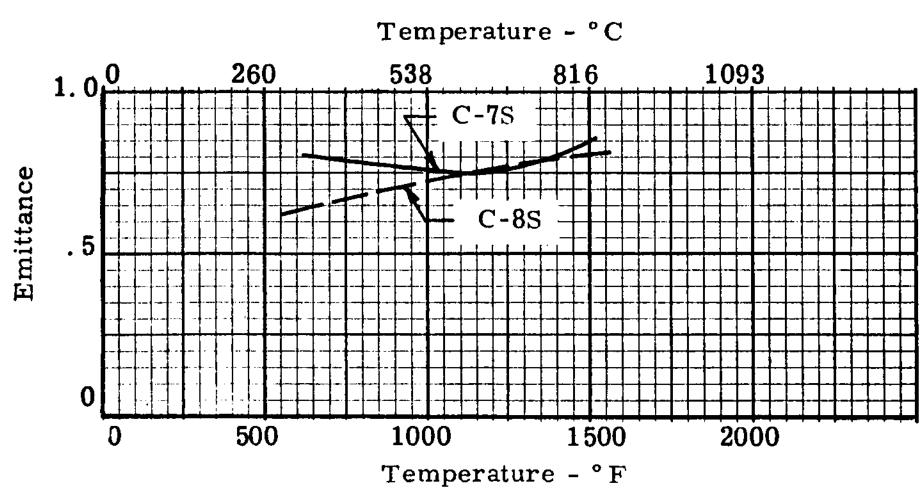


Figure 14. Comparison of Emittance of Smooth Copper Specimens with Chrycote Coating During the Second Run for Each Specimen.

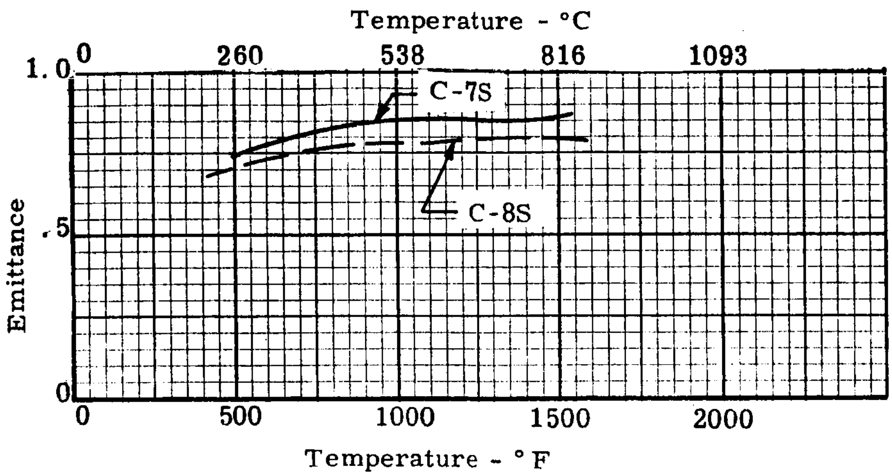
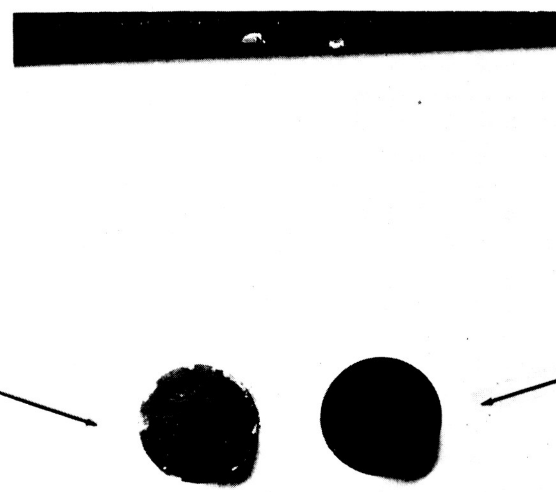


Figure 15. Comparison of Emittance of Smooth Copper Specimens with Chrycote Coating During the Third Run for Each Specimen.



Specimen C-7S
After Three Cycles
to Approximately
1472°F

Specimen C-8S
Before Exposure

Figure 16. Picture of Smooth Copper Specimen With Chrycote Coating Before and After Exposure in Air to About 1472°F (800°C)

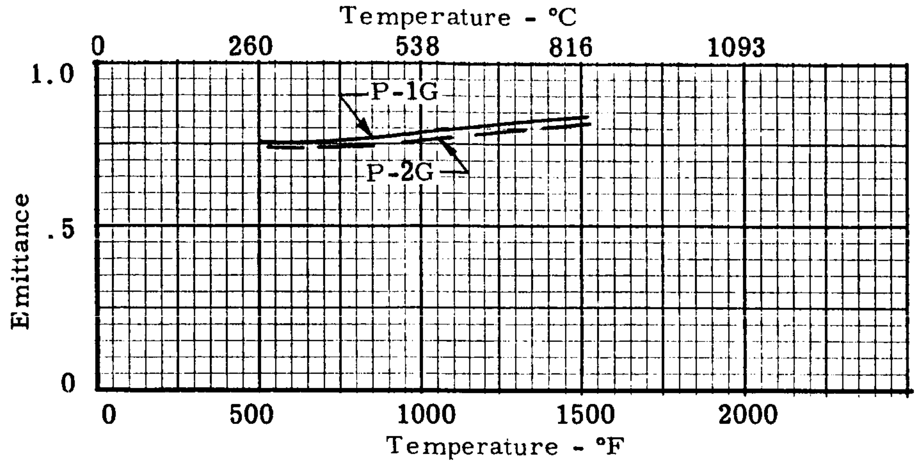


Figure 17. Comparison of Emittance of Grooved Copper Specimens With Platinum Black Coating During the First Run for Each Specimen

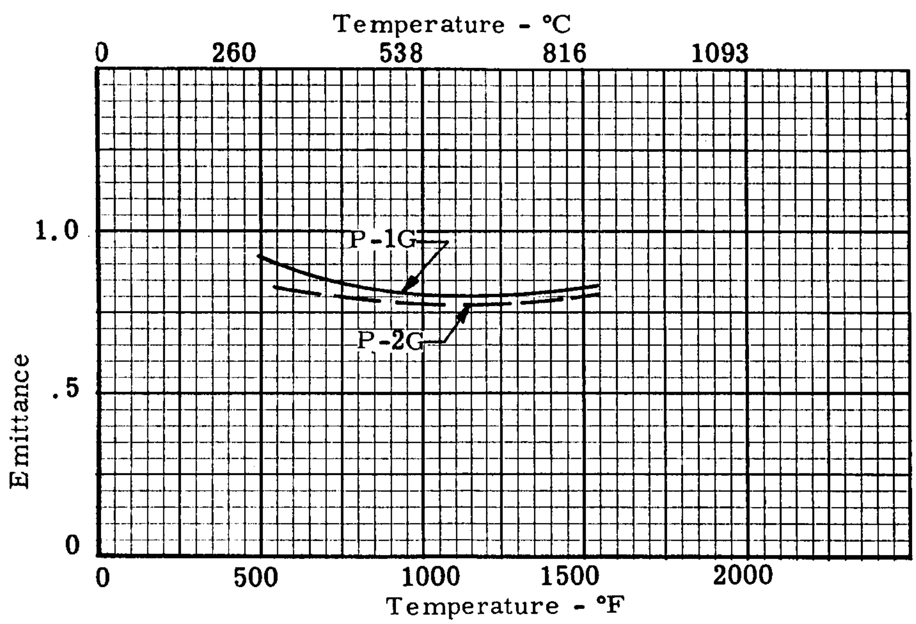


Figure 18. Comparison of Emittance of Grooved Copper Specimens With Platinum Black Coating During the Second Run for Each Specimen

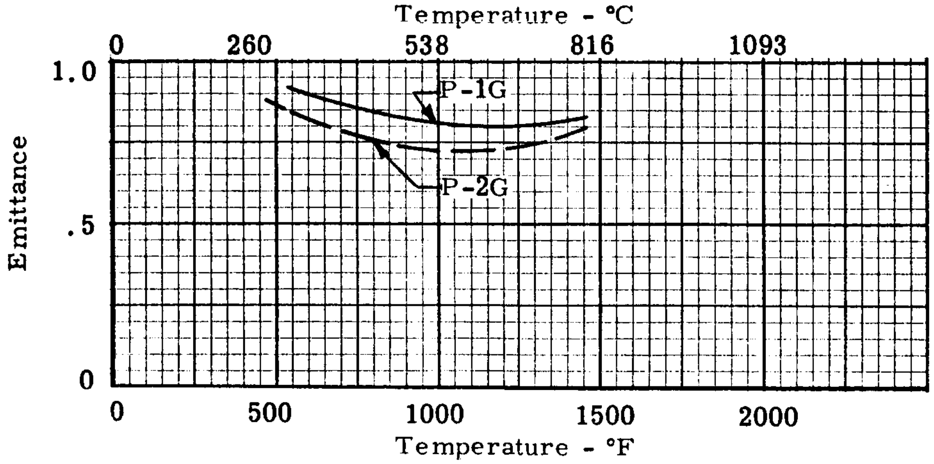


Figure 19. Comparison of Emittance of Grooved Copper Specimens With Platinum Black Coating During the Third Run for Each Specimen

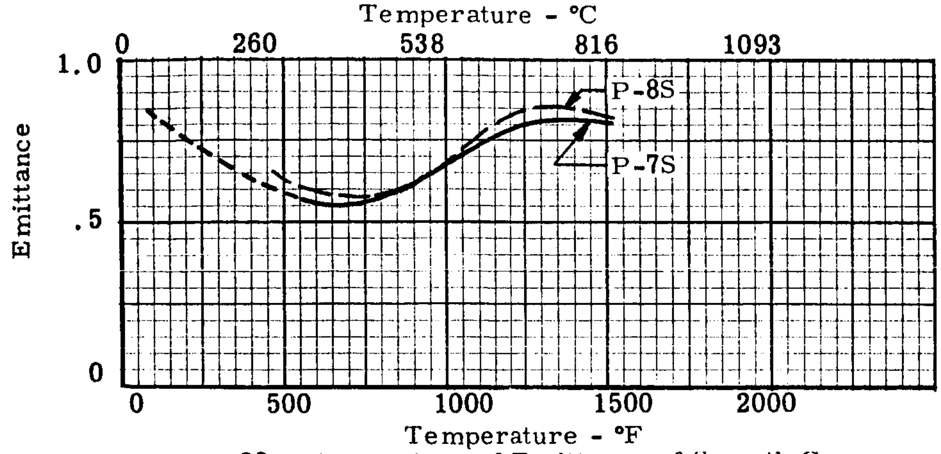


Figure 20. Comparison of Emittance of Smooth Copper Specimens With Platinum Black Coating During the First Run for Each Specimen

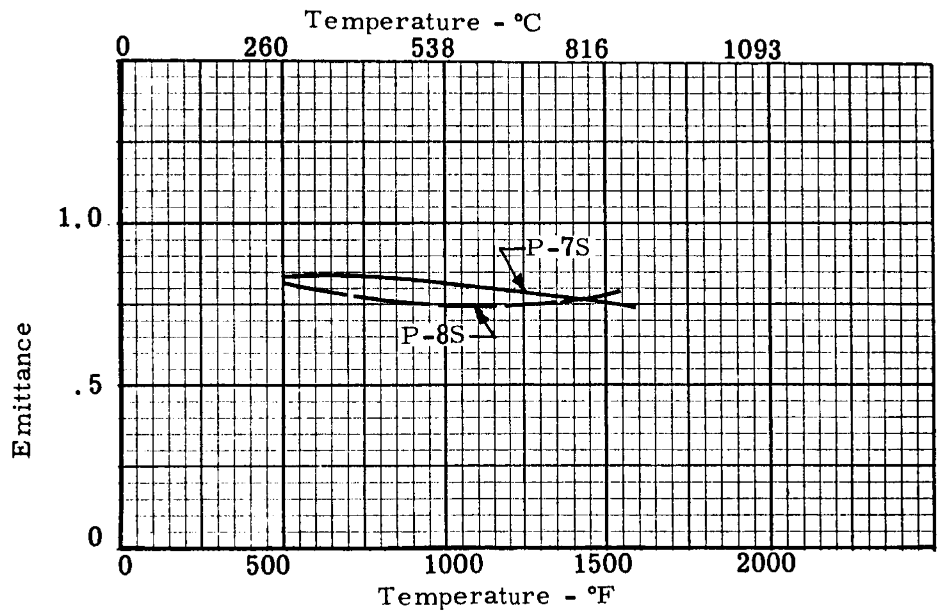


Figure 21. Comparison of Emittance of Smooth Copper Specimens With Platinum Black Coating During the Second Run for Each Specimen

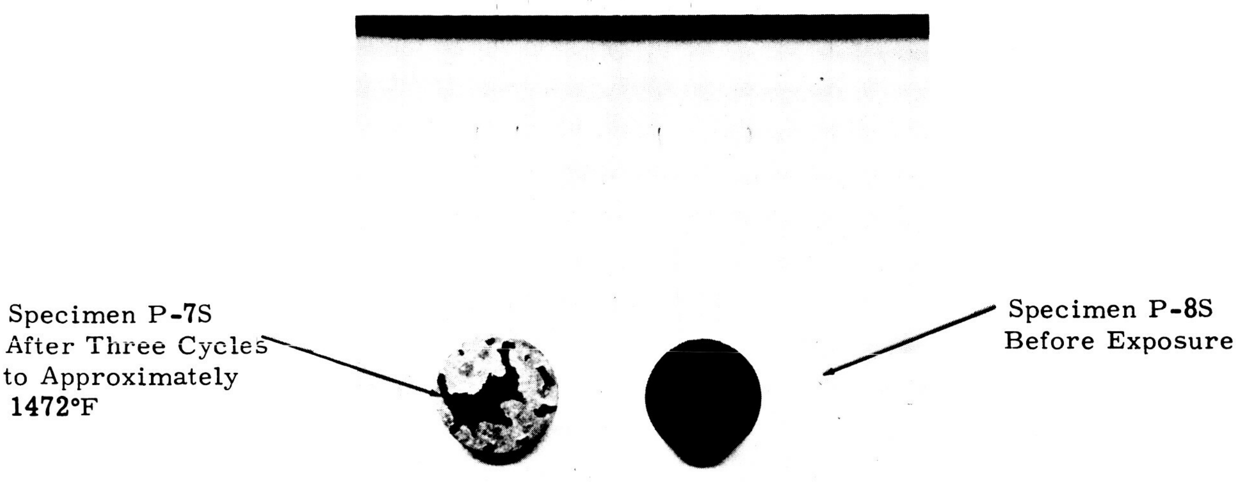


Figure 22. Picture of Smooth Copper Specimen With Platinum Black Coating Before and After Exposure in Air to About 1472°F (800°C)

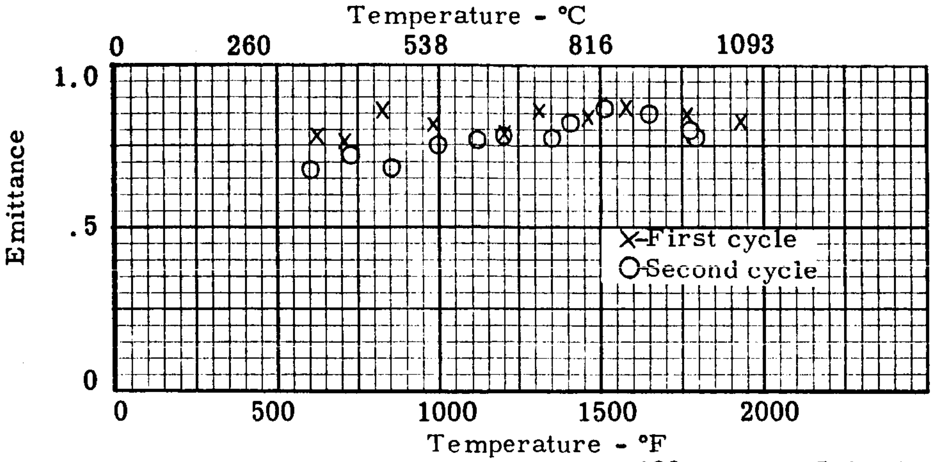


Figure 23. Effect of Cycling in Air to 100°F Below Softening Point on Emittance of Grooved Copper Specimen With Chrycote Coating for Successive Runs of Same Specimen (Specimen C-3G)

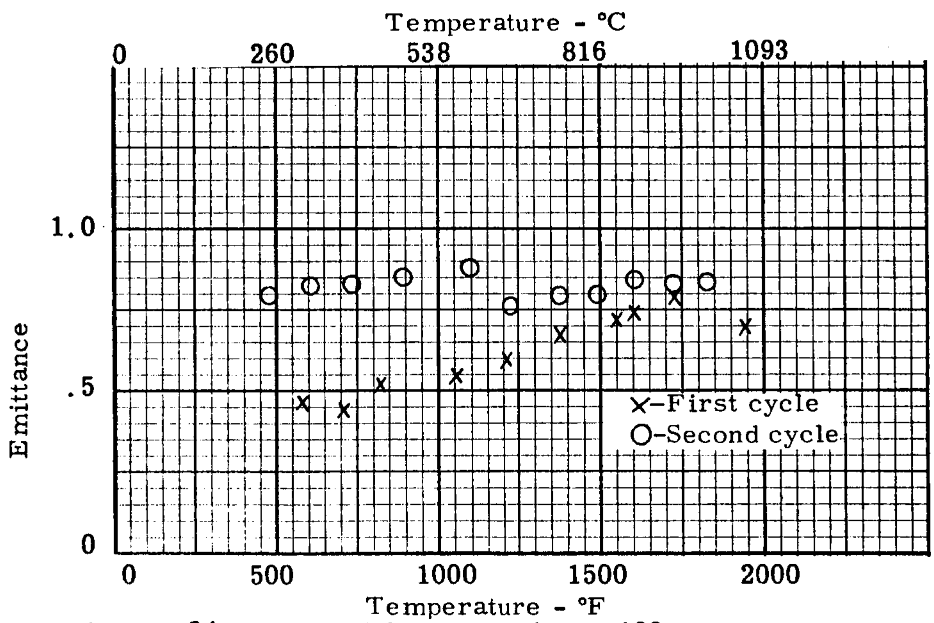


Figure 24. Effect of Cycling in Air to 100°F Below Softening Point on Emittance of Smooth Copper Specimen with Chrycote Coating for Successive Runs of Same Specimen (Specimen C-9S)

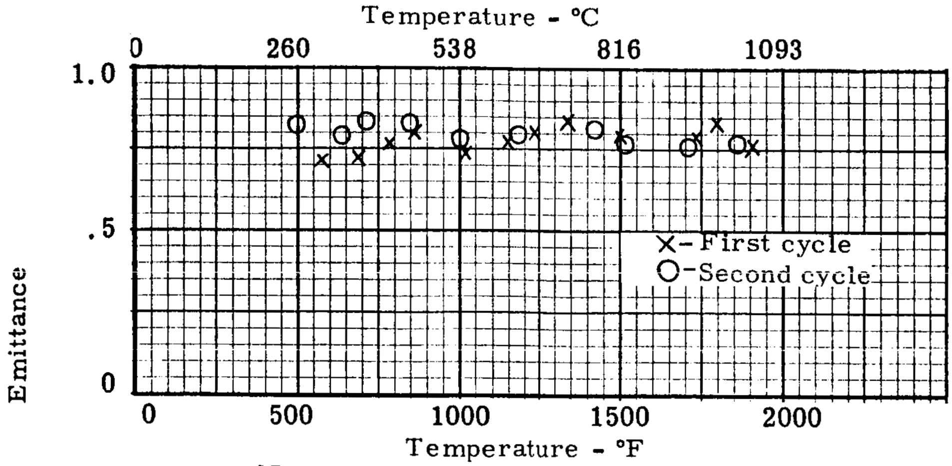


Figure 25. Effect of Cycling in Air to 100°F Below Softening Point on Emittance of Grooved Copper Specimen With Platinum Black Coating for Successive Runs on Same Specimen (Specimen P-3G)

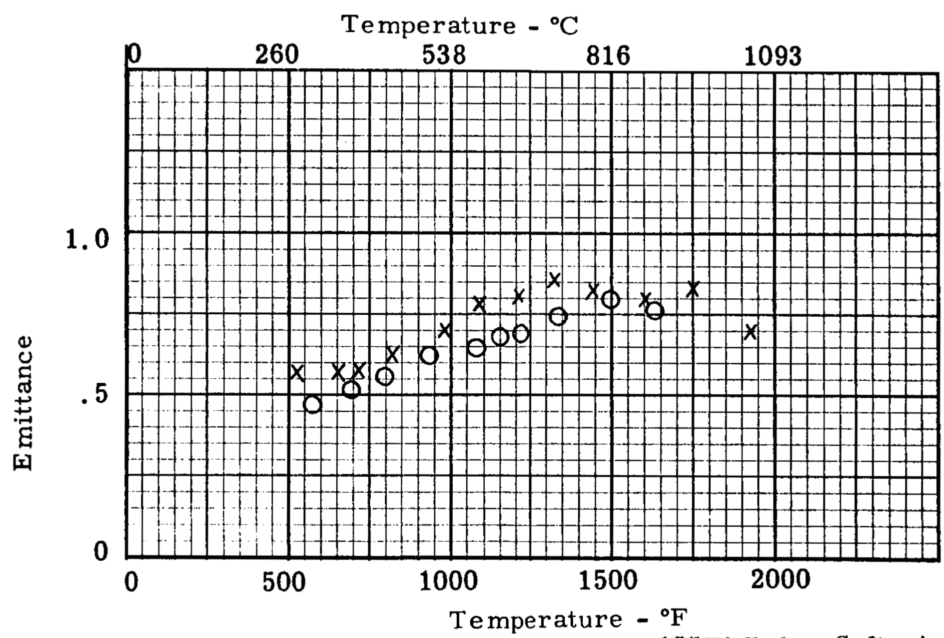


Figure 26. Effect of Cycling in Air to 100°F Below Softening Point on Emittance of Smooth Copper Specimen With Platinum Black Coating for Successive Runs on Same Specimen (Specimen P-9S)

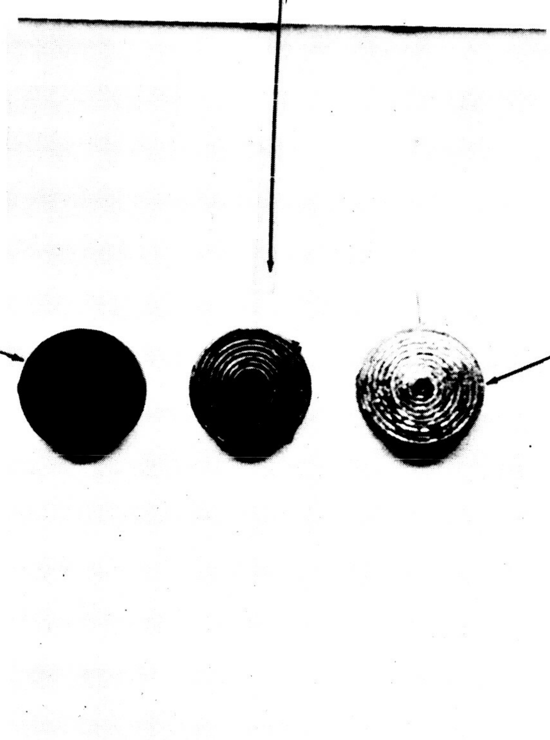


Figure 27. Picture of Grooved Copper Specimens with Chyrcote Coating Before and After Different Exposures in Air

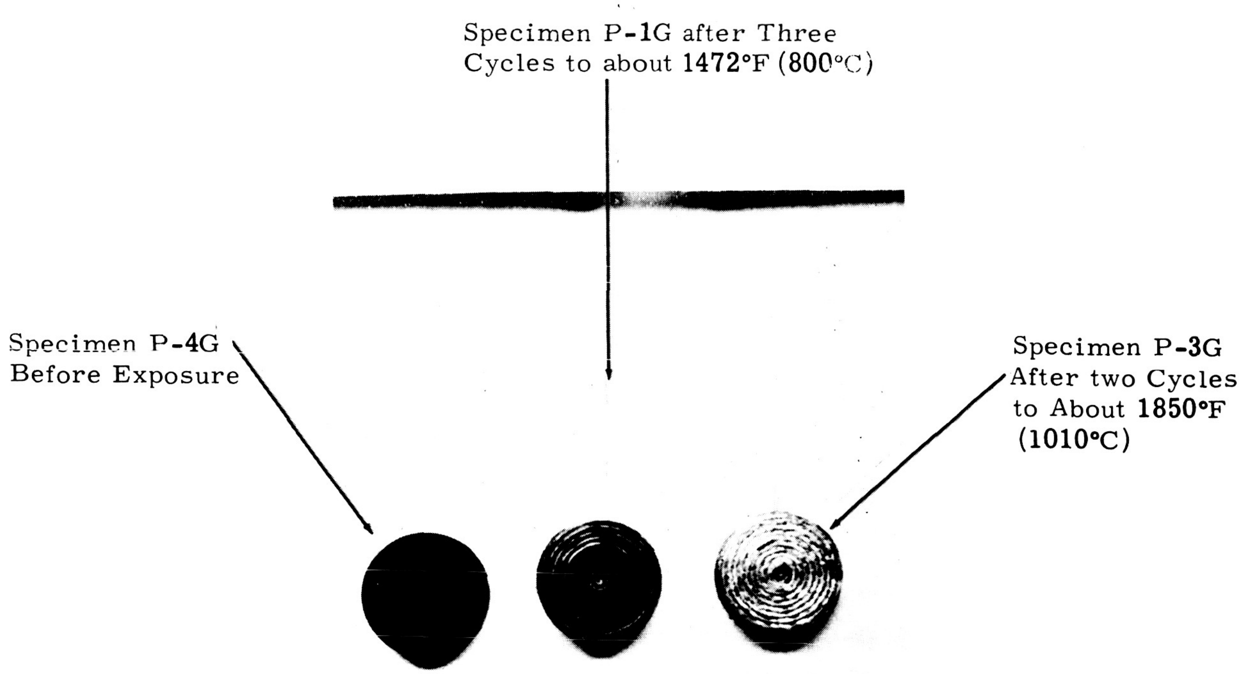


Figure 28. Picture of Grooved Copper Specimens with Platinum Black Coating Before and After Different Exposures in Air

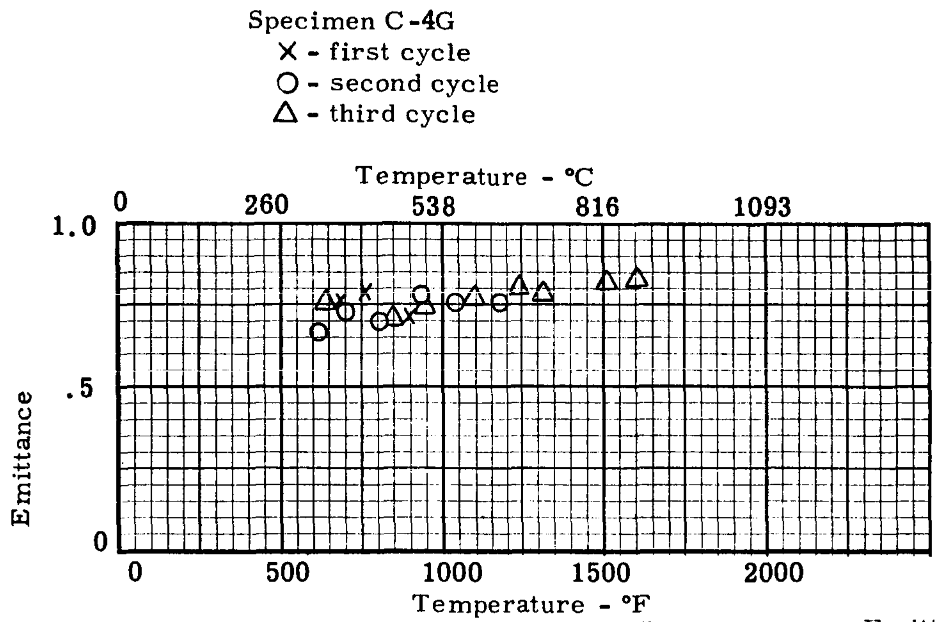


Figure 29. Effect of Prior Exposure Temperature on Emittance of Grooved Copper Specimen With Chrycote Coating for Successive Runs on Same Specimen

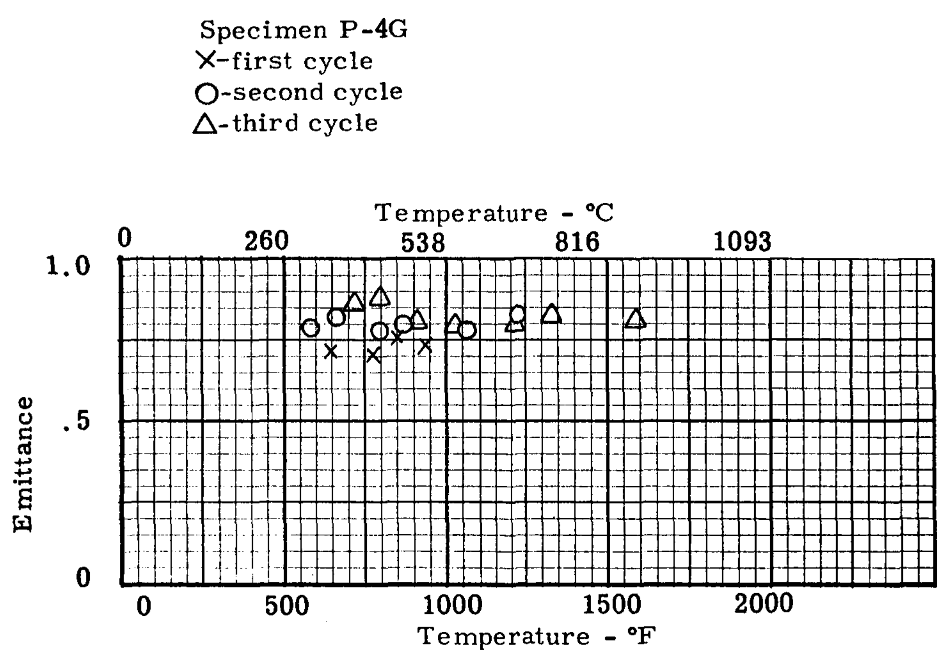


Figure 30. Effect of Prior Exposure Temperature in Air on Emittance of Grooved Copper Specimen With Platinum Black Coating for Successive Runs on Same Specimen

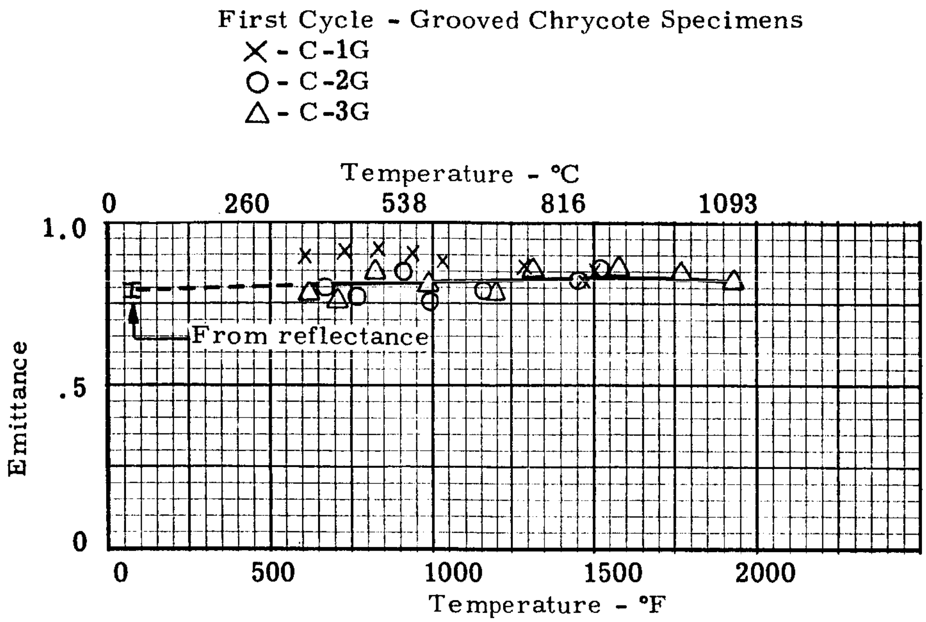


Figure 31. Composite Plot of Emittance Data for Grooved Copper Specimens With Chrycote Coating for First Run on All Specimens

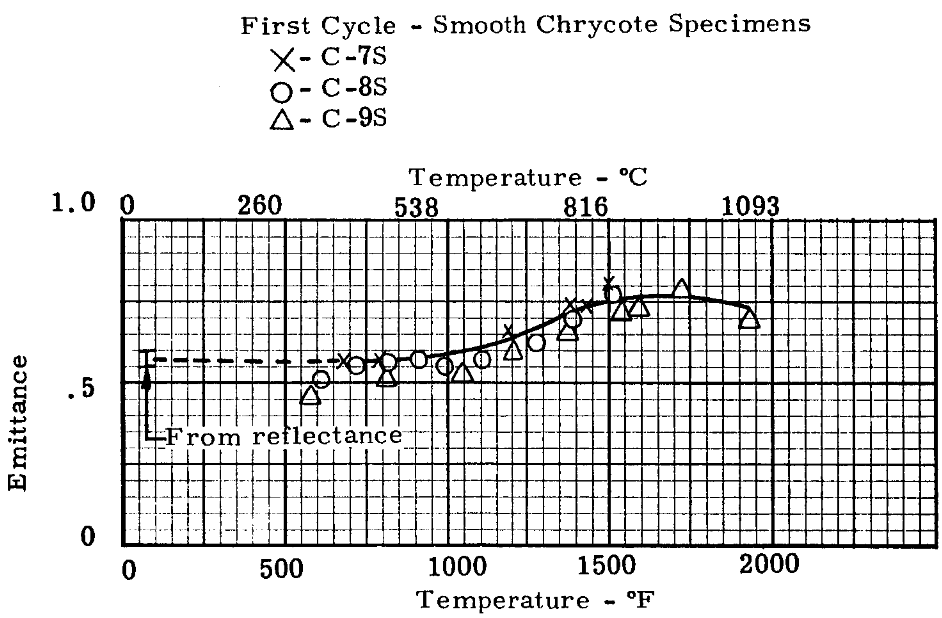


Figure 32. Composite Plot of Emittance Data for Smooth Copper Specimens With Chrycote Coating for First Run on All Specimens

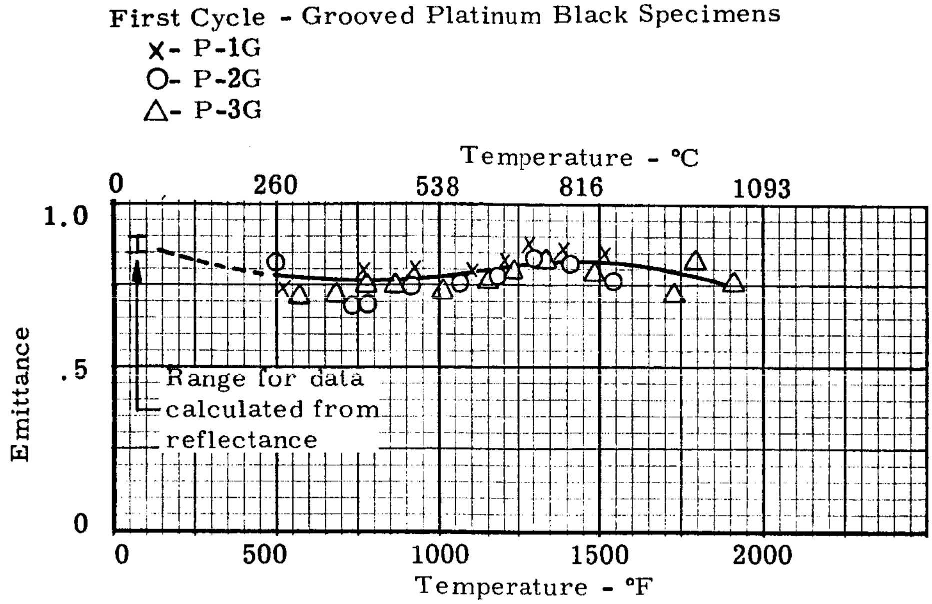


Figure 33. Composite Plot of Emittance Data for Grooved Copper Specimens With Platinum Black Coating for First Run on All Specimens

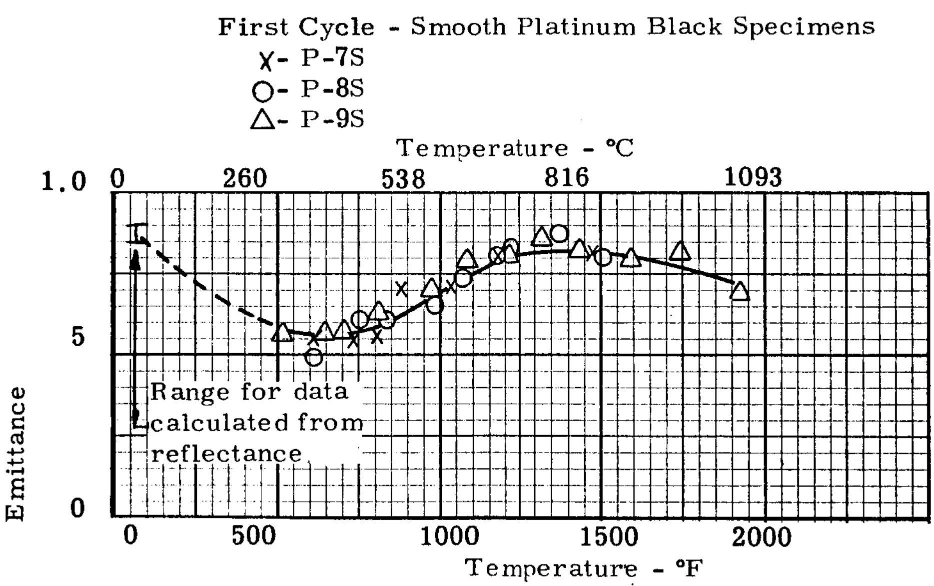


Figure 34. Composite Plot of Emittance Data for Smooth Copper Specimens With Platinum Black Coating for First Run on All Specimens

Table No. 1

Room Temperature Reflectance of Specimen C-1G
(Chrycote, grooved)

Run No. 3

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.140	.032	.32
.129	.028	.22
.132	.025	.19
.131	.026	.20
.132	.029	.22
		Average Reflectance = .21

Run No. 5

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.121	.031	.26
.122	.027	.22
.121	.030	.25
.120	.030	.25
.125	.026	.21
		Average Reflectance = .24

Table No. 2

Room Temperature Reflectance of Specimen C-2G
(Chrycote, grooved)

Run No. 3

Mirror	Net Radiometer Output Millivolts Specimen	Reflectance
.128	.025	.20
.128	.029	.23
.124	.023	.19
.123	.021	.17
.124	.024	.19
		Average Reflectance = .20

Run No. 5

Mirror	Net Radiometer Output Millivolts Specimen	Reflectance
.116	.024	.21
.116	.024	.21
.122	.026	.21
.122	.023	.19
.123	.024	.20
		Average Reflectance = .20

Table No. 3

Room Temperature Reflectance of Specimen C-7S
(Chrycote, smooth)

Run No. 6

Net Radiometer Output Millivolts Mirror	Specimen	Reflectance
.115	.042	.37
.117	.046	.39
.113	.043	.38
.116	.044	.38
.115	.044	.38
		Average Reflectance= .38

Run No. 7

Net Radiometer Output Millivolts Mirror	Specimen	Reflectance
.114	.054	.47
.115	.058	.50
.113	.058	.51
.112	.054	.48
.111	.055	.50
		Average Reflectance = .49

Table No. 4

Room Temperature Reflectance of Specimen C-8S
(Chrycote, smooth)

Run No. 5

Mirror	Net Radiometer Output Millivolts Specimen	Reflectance
.129	.046	.36
.125	.055	.44
.122	.054	.44
.120	.052	.43
.125	.055	.44
		Average Reflectance = .42

Run No. 6

Mirror	Net Radiometer Output Millivolts Specimen	Reflectance
.110	.041	.37
.113	.046	.41
.117	.045	.38
.113	.045	.40
.111	.045	.41
		Average Reflectance = .39

Table No. 5

Room Temperature Reflectance of Specimen P-1G
(Platinum, grooved)

Run No. 1

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.104	.013	.13
.103	.013	.16
.109	.016	.15
.109	.015	.14
		Average Reflectance = .145

Run No. 2

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.110	.010	.09
.111	.012	.11
.110	.012	.11
.108	.013	.12
		Average Reflectance= .11

Table No. 6

Room Temperature Reflectance of Specimen P-2G
(Platinum, grooved)

Run No. 1

Mirror	Specimen	Reflectance
	Net Radiometer Output Millivolts	
.112	.018	.16
.111	.018	.16
.111	.019	.17
.111	.020	.18
.111	.016	.14
		Average Reflectance = .16

Run No. 2

Mirror	Specimen	Reflections
	Net Radiometer Output Millivolts	
.107	.014	.13
.106	.016	.15
.110	.013	.12
.108	.012	.11
.110	.012	.11
		Average Reflectance = .12

Table No. 7

Room Temperature Reflectance of Specimen P-7S
(Platinum, smooth)

Run No. 1

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.112	.026	.23
.112	.020	.18
.110	.017	.15
.110	.020	.18
.108	.020	.19
		Average Reflectance= .19

Run No. 2

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.104	.014	.13
.114	.017	.15
.114	.015	.13
.111	.014	.13
.111	.014	.13
		Average Reflectance= .13

Table No. 8

Room Temperature Reflectance of Specimen P-8S
(Platinum, smooth)

Run No. 1

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.110	.020	.18
.110	.020	.18
.110	.018	.16
.110	.021	.19
.110	.019	.17
		Average Reflectance= .18

Run No. 2

Net Radiometer Output Millivolts		
Mirror	Specimen	Reflectance
.110	.010	.09
.108	.018	.17
.112	.015	.13
.111	.014	.13
.111	.014	.13
		Average Reflectance= .13

Table No. 9

Emittance to 1472° F (800° C) for Successive Runs in Air of Specimen C-1G (Chrycote, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts		Emittance	Remarks
	from Specimen	from Blackbody		
First Cycle				
528	.012	.0123	.98	
607	.016	.0179	.89	
729	.026	.0286	.91	
829	.037	.0405	.91	
934	.050	.056	.89	
1028	.065	.074	.88	
1084	.082	.0865	.95	
1287	.123	.145	.85	
1411	.146	.198	.74	
1456	.177	.218	.81	
1489	.192	.230	.84	
Second Cycle				
504	.010	.011	.91	
651	.017	.0212	.80	
768	.027	.033	.82	
806	.032	.0378	.85	
943	.050	.0582	.86	
1000	.057	.069	.83	
1087	.076	.087	.87	
1312	.134	.158	.85	
1422	.168	.204	.82	
1548	.209	.262	.80	

Table No. 9 (Con'd)

Emittance to 1472°F (800°C) for Successive Runs in Air of Specimen C-1G (Chrycote, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
Third Cycle				
587	.014	.0163	.86	
744	.025	.0302	.83	
803	.029	.0373	.78	
879	.041	.0480	.85	
1065	.069	.082	.84	
1201	.095	.119	.80	
1314	.132	.158	.84	
1396	.161	.189	.85	
1529	.216	.250	.86	

Table No. 10

Emittance and Change in Emittance to 1472°F (800°C) of Specimen C-2G (Chrycote, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
507	.010	.0113	.89	
666	.018	.0225	.80	
761	.025	.0322	.78	
905	.044	.0520	.85	
986	.050	.0660	.76	
1301	.122	.154	.79	
1464	.180	.218	.83	Unable to view specimen fully through auxiliary port.
1515	.213	.245	.87	
Second Cycle				
510	.009	.0115	.78	
706	.023	.0263	.88	
872	.040	.0468	.86	
964	.056	.0625	.90	
1061	.070	.082	.85	
1220	.106	.123	.86	
1307	.132	.155	.85	
1397	.167	.190	.88	
1514	.216	.245	.88	
Third Cycle				
510	.011	.0114	.97	
742	.027	.0300	.90	
888	.042	.0492	.85	
1026	.064	.0740	.87	
1157	.089	.0105	.85	
1334	.145	.162	.90	
1435	.182	.208	.88	
1495	.207	.232	.89	

Table No. 11

Emittance and Change in Emittance to 1472°F (800°C) of Specimen C- 7S (Chrycote, smooth)

True Thermocuple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
511	.005	.0114	.44	
674	.013	.0232	.56	
790	.020	.0355	.56	
926	.031	.0550	.56	
1105	.055	.093	.59	
1185	.074	.113	.66	
1379	.136	.184	.74	
1424	.149	.204	.73	
1498	.186	.232	.80	Surface coat cracking
Second Cycle				
658	.016	.0219	.73	
808	.029	.0380	.76	
1094	.066	.0885	.75	
1261	.112	.137	.82	
1338	.127	.165	.77	
1466	.185	.220	.84	
1499	.199	.235	.85	
Third Cycle				
525	.009	.0122	.74	
726	.020	.0280	.71	
831	.038	.0405	.94	
941	.052	.0578	.90	
1133	.088	.0980	.90	
1212	.106	.122	.87	
1346	.144	.168	.86	
1489	.193	.227	.85	

Table No. 12

Emittance and Change in Emittance to 1472°F (800°C)
of Specimen C-8S (Chrycote, smooth)

True Thermocouple Temperature	Radiometer Output Millivolts		Emittance	Remarks
	from Specimen	from Blackbody		
First Cycle				
524	.005	.0122	.41	
606	.009	.0178	.51	
719	.015	.0274	.55	
817	.022	.0388	.57	
906	.029	.0507	.57	
990	.037	.0670	.55	
1102	.053	.091	.58	
1276	.089	.142	.63	
1385	.127	.183	.69	
1509	.187	.243	.77	
Second Cycle				
543	.008	.0133	.60	
699	.017	.0254	.67	
813	.025	.0379	.66	
980	.048	.0647	.74	
1059	.060	.0818	.73	
1236	.100	.128	.78	
1335	.134	.165	.81	
1418	.153	.200	.77	
1575	.227	.278	.82	
Third Cycle				
478	.007	.01	.7	.01 is an estimate from black body calibration curve.
626	.013	.0193	.67	
753	.025	.0312	.80	
896	.039	.0501	.78	
1038	.059	.0770	.77	
1295	.120	.149	.81	
1368	.142	.178	.80	
1556	.212	.265	.80	

Table No. 13

Emmittance and Change in Emittance to 1472°F (800°)
of Specimen P-1G (Platinum, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
522	.009	.0121	.74	
666	.020	.0225	.89	
766	.026	.0328	.79	
917	.042	.0530	.79	
1097	.070	.089	.79	
1197	.096	.117	.82	
1282	.126	.144	.88	
1384	.159	.185	.86	
1516	.204	.242	.84	
Second Cycle				
496	.010	.0108	.93	
597	.015	.0171	.88	
739	.024	.0295	.81	
839	.034	.0415	.82	
932	.047	.0557	.84	
1034	.059	.0755	.78	
1259	.110	.136	.81	
1356	.139	.173	.80	
1434	.168	.207	.81	
1510	.200	.242	.83	
Third Cycle				
507	.009	.0113	.80	
589	.015	.0164	.92	
859	.037	.0444	.83	
983	.051	.0650	.79	
1194	.090	.115	.78	
1287	.118	.145	.81	
1374	.151	.180	.84	
1479	.183	.225	.81	

Table No. 14

Emittance and Change in Emittance to 1472°F (800°C)
of Specimen P-2G (Platinum, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts		Emittance	Remarks
	from Specimen	from Blackbody		
First Cycle				
499	.009	.0109	.83	
610	.011	.0182	.60	
735	.020	.0290	.69	
789	.025	.0355	.70	
907	.039	.0510	.77	
1062	.062	.0817	.76	
1165	.085	.108	.79	
1321	.132	.158	.84	
1417	.162	.198	.82	
1541	.194	.258	.75	
Second Cycle				
598	.014	.0172	.81	
735	.023	.0288	.80	
805	.028	.0372	.75	
872	.033	.0464	.71	
1006	.053	.0705	.75	
1152	.076	.103	.74	
1223	.094	.123	.76	
1348	.128	.166	.77	
1453	.171	.215	.80	
1517	.191	.243	.79	
Third Cycle				
508	.010	.0114	.88	
620	.015	.0189	.79	
789	.026	,0353	.74	
897	.038	.0502	.76	
991	.049	.0670	.73	
1182	.082	.113	.73	
1350	.129	.170	.76	
1492	.185	.229	.81	

Table No. 15

Emittance and Change in Emittance to 1472° F (800° C) of Specimen P-7S (Platinum, smooth)

True Thermocouple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
489	.008	.0103	.78	
616	.011	.0184	.60	
733	.017	.0288	.59	
808	.023	.0375	.61	
886	.035	.0492	.71	
1046	.056	.0784	.71	
1179	.089	.111	.80	
1351	.146	.171	.85	
1481	.186	.228	.82	Specimen flaking badly.
Second Cycle				
503	.009	.0111	.81	
641	.017	.0202	.84	
720	.023	.0273	.84	
778	.030	.0344	.87	
875	.037	.0470	.79	
1124	.072	.096	.75	
1202	.096	.117	.82	
1326	.121	.160	.76	
1583	.214	.282	.76	Apparatus not opened.
Third Cycle				
498	.004	.0109	.37	
653	.009	.0212	.43	
701	.014	.0256	.55	
818	.020	.0384	.52	
891	.027	.0496	.54	
1067	.043	.0834	.52	
1116	.058	.094	.62	
1246	.084	.132	.64	
1351	.118	.170	.69	
1478	.179	.224	.80	Large flake laying on specimen surface.

Table No. 16

Emittance and Change in Emittance to 1472° F (800° C)
of Specimen P-8S (Platinum, smooth)

True Thermocouple Temperature °F	Radiometer Output Millivolts		Emittance	Remarks
	from Specimen	from Blackbody		
First Cycle				
496	.007	.0107	.65	
612	.009	.0182	.50	
757	.019	.0316	.60	
837	.025	.0412	.61	
991	.044	.0670	.66	
1068	.061	.0821	.74	
1191	.092	.113	.81	
1226	.105	.124	.85	
1371	.154	.176	.88	
1499	.189	.234	.81	Specimen flaked badly around edges.
Second Cycle				
520	.010	.0120	.83	
639	.016	.0201	.80	
765	.025	.0327	.77	
913	.039	.0514	.76	
1070	.060	.0813	.74	
1183	.085	.111	.77	
1308	.115	.155	.74	
1413	.152	.197	.77	
1497	.183	.232	.79	Specimen began flaking upon inspection and continued until all the coating had popped off.

Table No. 17

Effect on Emittance of Cycling in Air to 100°F
Below Softening Point of Copper - Specimen C-3G
(Chrycote, grooved) for Successive Runs on Same Specimen

True Thermocouple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
507	.010	.0113	.89	
626	.015	.0192	.78	
712	.020	.0265	.76	
827	.034	.0400	.85	
986	.054	.0665	.81	
1202	.093	.119	.78	
1314	.134	.157	.85	
1466	.185	.221	.84	
1576	.242	.279	.87	
1768	.338	.402	.84	
1933	.429	.520	.83	Thermocouple burned out on cooling - specimen badly flaked.
Second Cycle				
557	.007	.0141	.50	Thermocouple peened to back of specimen.
604	.012	.0176	.68	
722	.020	.0274	.73	
857	.030	.0441	.68	
997	.052	.0684	.76	
1120	.073	.095	.77	
1202	.094	.119	.79	
1355	.124	.170	.73	
1418	.165	.198	.83	
1516	.212	.244	.87	
1649	.272	.320	.85	
1774	.327	.410	.80	
1796	.324	.419	.77	

Table No. 18

Effect of Emittance of Cycling in Air to 100 ^{0}F
Below Softening Point of Copper - Specimen C-9S
(Chrycote, smooth) for Successive Runs on Same Specimen

True Thermocouple Temperature ^{0}F	Radiometer Output Millivolts		Emittance	Remarks
	from Specimen	from Blackbody		
First Cycle				
572	.007	.0152	.46	Thermocouple welded.
700	.011	.0255	.43	
818	.020	.0389	.51	
1046	.042	.0790	.53	
1209	.071	.121	.59	
1374	.121	.182	.67	
1547	.189	.264	.72	
1588	.209	.286	.73	
1731	.296	.379	.78	
1937	.358	.522	.69	Thermocouple burned out on cooling.
Second Cycle				
476	.008	.01	.8	Thermocouple peened on back of specimen. 476^{0} - off Black-body calibration heat
596	.014	.0170	.82	
722	.023	.0278	.83	
890	.042	.0495	.85	
1094	.078	.0888	.88	
1219	.093	.122	.76	
1371	.143	.180	.79	
1485	.184	.230	.80	
1597	.242	.289	.84	
1719	.305	.370	.82	
1827	.371	.446	.83	

Table No. 19

Effect of Emittance of Cycling in Air to 100^0F
Below Softening Point of Copper - Specimen P-3G
(Platinum, grooved) for Successive Runs on Same Specimen

True Thermocouple Temperature ^0F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
576	.011	.0153	.72	Thermocouple peened.
691	.018	.0249	.72	
778	.026	.0341	.76	
856	.033	.0438	.75	
1012	.053	.0720	.74	
1150	.080	.103	.78	
1234	.102	.127	.80	
1342	.139	.166	.84	
1496	.184	.233	.79	
1729	.276	.376	.73	
1790	.345	.413	.84	
1917	.393	.518	.76	
Second Cycle				
499	.009	.0108	.83	
639	.016	.0201	.80	
718	.023	.0274	.84	
851	.036	.0432	.83	
998	.051	.0693	.74	
1180	.089	.112	.80	Flaked coating noted on surface of specimen.
1277	.114	.142	.80	
1425	.166	.201	.83	
1512	.186	.241	.77	
1714	.283	.370	.77	
1855	.359	.465	.77	

Table No. 20

Effect of Emittance of Cycling in Air to 100^0F
Below Softening Point of Copper - Specimen P-9S
(Platinum, smooth) for Successive Runs on Same Specimen

True Thermocouple Temperature ^0F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				
521	.007	.0122	.57	
647	.012	.0210	.57	
708	.015	.0262	.57	
817	.024	.0386	.62	
978	.045	.0647	.70	
1088	.069	.087	.79	
1209	.098	.121	.81	
1325	.136	.159	.86	
1444	.176	.213	.83	
1596	.230	.289	.80	
1749	.317	.384	.83	
1925	.363	.520	.70	Apparatus not opened.
Second Cycle				
564	.007	.0148	.47	
692	.013	.0250	.52	
794	.022	.0358	.62	
932	.035	.0555	.63	
1074	.055	.0845	.65	
1149	.070	.103	.68	
1218	.085	.123	.69	
1337	.123	.165	.75	
1494	.185	.231	.80	
1632	.236	.308	.77	Temperature above 1632 not recorded due to thermocouple failure.

Table No. 21

Effect of Prior Exposure Temperature in Air
on Emittance of Specimen C-4G (Chrycote, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts from Specimen	Radiometer Output Millivolts from Blackbody	Emittance	Remarks
First Cycle				Thermocouple welded.
497	.007	.0108	.65	
678	.018	.0237	.76	
754	.025	.0313	.80	
899	.037	.0510	.73	Specimen tempera- ture before recycle - 107°F.
Second Cycle				
511	.009	.0114	.79	
609	.012	.0180	.67	
701	.019	.0258	.74	
804	.026	.0371	.70	
939	.044	.0569	.77	
1040	.059	.0775	.76	
1175	.085	.111	.77	Specimen temperature before recycle 80°F.
Third Cycle				
495	.009	.0107	.84	
645	.016	.0209	.77	
759	.025	.0319	.78	
848	.031	.0430	.72	
952	.045	.0600	.75	
1091	.069	.0878	.79	
1241	.106	.130	.82	
1313	.125	.157	.80	
1529	.210	.251	.84	
1593	.257	.288	.89	

Table No. 22

Effect of Temperature Cycling on Emittance of
Specimen P-4G (Platinum, grooved)

True Thermocouple Temperature °F	Radiometer Output Millivolts		Emittance	Remarks
	from Specimen	from Blackbody		
First Cycle				
523	.008	.0121	.66	
647	.015	.0209	.72	
783	.025	.0349	.72	
852	.033	.0434	.76	
878	.035	.0478	.73	Specimen temperature before re-cycle - 105°F.
Second Cycle				
494	.010	.0106	.94	
589	.013	.0164	.79	
669	.019	.0228	.83	
793	.028	.0353	.79	
887	.040	.0496	.81	
1055	.063	.0803	.79	
1229	.102	.123	.83	Specimen temperature before recycle - 75°F.
Third Cycle				
724	.023	.0280	.82	
803	.033	.0370	.89	
917	.043	.0530	.81	
1030	.061	.0758	.81	
1220	.098	.122	.80	
1340	.140	.166	.84	
1594	.231	.284	.81	

APPENDIX

TOTAL NORMAL EMITTANCE TO 5000°F

REFLECTANCE MEASUREMENTS AT ROOM TEMPERATURE

TOTAL NORMAL EMITTANCE TO 5000°F

General

Emittance is measured by comparing the energy received by a radiometer from the sample to that received from a black body cavity maintained at the same temperature.

The equipment may be divided into three main parts: the induction heating furnace, the radiometer, and the temperature measurement equipment. Figure 1 shows a picture of the complete equipment.

Description of Apparatus

A cross section of the apparatus is shown in Figure 2. The specimen (1) is supported in the center of the flat concentrator induction coil (2) by a zirconia cylinder filled with fine zirconia grog and tungsten wires (3). The zirconia cylinder rests on a crucible filled with coarse zirconia grog (4). The radiometer (5) views the specimen from directly above through a water-cooled tube (6). A water-cooled optical valve (7) is used to blank off the specimen from the radiometer. Optical-temperature readings are taken through the main port (8), which may be pushed in to view the specimen through a mirror (9) from directly above. When radiometer readings are being taken, the main port is pulled out and away from the line of sight of the radiometer. Auxiliary port (10) is used to view the specimen directly as a check for the main port. Both viewing ports contain sapphire windows. The portion of the furnace above the specimen (11) is water-cooled to eliminate any possibility of energy being reflected back onto the specimen surface. The emittance furnace is built of steel and sealed with "O" rings so that a vacuum may be attained.

The radiometer, see Figure 3, was constructed according to Snyder[1] and Gier[2] with some modifications. The receiver element consists of approximately 160 turns of No. 40 AWG bare-constantan wire (104 turns

1 Snyder, N. W., Gier, J. T., and Dunkle, R. V., "Total Normal Emissivity Measurements on Aircraft Materials Between 100 and 1000°F," Trans. of the A. S. M. E., Vol. 77, 1944, p. 1011.

2 Gier, J. T., and Boelter, L. M. K., "The Silver-Constantan Plated Thermopile," Temperature - Its Measurement and Control in Science and Industry, American Institute of Physics, 1941, p. 1284.

per inch) wound around a plastic insulator strip about 2" long by $1\frac{5}{8}$" wide by $\frac{5}{16}$" thick. Silver was electroplated in several stages onto the constantan coil so that two $\frac{1}{8}$" wide lines of silver-constantan junctions, $\frac{1}{2}$" apart, were formed on the same side of the coil and across all of the wire turns. The remainder of the entire coil was silver plated. Each of the two lines of junctions was covered with a thin, narrow strip of black paper. One of these junction lines is designated as the active or "hot" junction and is placed to receive energy from the sample. The other is shielded and termed the passive or "cold" junction.

In order to shield the element from extraneous radiation, a cylindrical housing is placed immediately around the thermopile. The front of the housing contains a rectangular opening $\frac{1}{4}$" by $1\frac{1}{2}$" to allow the element to "see" the specimen. The actual limiting of the receiver field is accomplished by this rectangular slit and the $\frac{1}{4}$" round stop (12) just above the specimen. Additional stops in the water-cooled tube were installed as an added insurance to further minimize spurious reflections. The radiometer views the specimen directly. This eliminates the possibility of dirty lenses affecting the reading and, also, eliminates the spectral selectivity of the different types of materials used as windows.

The voltage generated by the receiver is measured with a Type K-3 Leeds and Northrup potentiometer in conjunction with an L and N Type 2430 DC galvanometer of 0.43 microvolts per millimeter deflection sensitivity. Temperatures are measured with a Leeds and Northrup portable potentiometer.

The receiver element was calibrated against a carbon-filament lamp of known radiation[3] and demonstrated a sensitivity of 8.66 Btu/hr/sq ft/millivolt.

The radiometer was checked, also, against an Eppley thermopile with 12 bismuth-silver junctions and a 1-mm quartz window and agreed within 10% scatter of data points. By factory calibration the sensitivity of the Eppley thermopile is 0.048 microvolts/microwatt/sq cm.

The optical pyrometers used are L and N catalog type 8622 calibrated in accordance with the International Critical Table of 1948 for an emittance of unity.

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3 Lamp No. C584, calibration by the National Bureau of Standards and reported in NBC Report 132737 A, July 1, 1952.

Calibration Procedure

To calibrate the radiometer for black body radiation, a black body cavity with a 6 to 1 aspect ratio made from graphite was used. The black body cavity was insulated by zirconia grog and lamp black placed in the annulus between the black body and the load coil, see Figure 4.

The accurate determinations of the specimen and black body temperatures are essential to good data. For the cavity-type black body, the temperatures are determined relatively easily by (1) thermocouples placed in the bottom of the cavity; (2) thermocouples dropped into the cavity; and (3) optical pyrometer observations. Up to 3000°F, agreement to within 15°F has been obtained regularly between these three readings. Above 3000°F the agreement between tungsten-rhenium couples and the optical pyrometer has been generally within 50°F or the repeatability of this type of thermocouple. Actually, the optical readings have no error other than those of the instrument calibration and the human error, which appears to provide a readout scatter of about 20°F at 4000°F.

Radiometer output versus temperature for black body radiation is plotted in Figure 5. Notice that the output is essentially linear from 2500°F to 5000°F with a slight curvature below 2000°F. As in house standards, the emittance of 304 stainless steel, tarnished tungsten, and graphite were measured, see Figure 6. The emittance of the stainless steel ranged from 0.15 at 700°F to 0.67 at 2000°F. These values are in close agreement with the literature values. The sanded CS graphite, also, checked out closely with the literature with values from 0.95 to 0.98.

Operating Procedures

The specimen is placed directly on the surface provided by the zirconia tube, grog, and tungsten wires. However, if the material of interest cannot be heated inductively, tungsten and tantalum heating discs are placed under the specimen with the specimen in contact with the tungsten disc.

The furnace is then evacuated to 15 mm of Hg and filled with high-purity, dry argon. This operation is carred out at least twice to assure an inert atmosphere. Throughout the run a slight pressure is maintained in the furnace by an argon purge, which is brought in through the radiometer enclosure and exhausted from the furnace housing, see Figure 2. In addition to maintaining an inert atmosphere, the purge flow tends to keep fumes away from the radiometer.

The temperature of the specimen is raised and maintained at the desired point by transferring energy to the specimen through the induction coil. About three hours are required to complete a single run with the temperature increasing stepwise but in uniform intervals. At each temperature level a radiometer reading is taken in conjunction with the temperature readings.

To obtain the radiometer reading, the following procedure is followed: As the specimen is heated, the blank-off valve is shut so that the thermopile can see no impulse. When the specimen temperature reaches steady state, a zero reading is obtained for the thermopile output. This reading is usually in the order of $\pm$ 0.002 millivolts. The blank-off valve is then opened, and the thermopile output increases several fold in a few seconds. The reading levels off as heat is transferred down the wires to the cold junction. The radiometer output is taken at the peak reading immediately after steady state. The net reading for that temperature is then obtained as the difference between the zero and steady-state reading.

If the blank-off valve were left open, the thermopile output would decrease slowly with time. After about 10 minutes, this reading might decrease by 50%; however, if the blank-off valve were shut and a new zero reading obtained, the difference between this new output and zero reading would be about the same as the original readings. The variation might be about 5 to 10%. The shift in readings is a result of the heating of the cold junctions.

The purge to the radiometer housing has no influence on the readings within the ranges at which the purge is operated. To determine this limit, the purge rate was increased to about 10 times the normal metered reading, and a small shift in readings of less than 1% was noted.

The temperature of the specimen is monitored by (1) thermocouples mounted directly on the target surface (usually held in place by a small zirconia pad) and (2) optical pyrometer readings on the target surface. Low temperature readings were made with thermocouples; however, in the intermediate temperature range from 1600°F to 2700°F a cross check was made between the thermocouple readings and the optical readings. The high-temperature measurements are made with an optical pyrometer. A main-port optical and an auxiliary-port optical-temperature reading are taken at each temperature level. The auxiliary-port temperature is normally used only as a check; however, if conditions warrant, such as a dirty main-port window or mirror, the auxiliary-port value may be used. Usually very good agreement is maintained between the main-port and auxiliary-port optical readings.

Emittance Calculation

The optical temperature readings must first be corrected to obtain true temperatures. The main-port reading is corrected for the sapphire window and mirror while the auxiliary-port reading is correct for the sapphire window and the angle at which the port views the specimen. The corrections are shown as curves in Figure 7.

After assuming an arbitrary-initial, emittance value, the brightness temperature is corrected for this assumed emittance, see Figure 8. The black body output is then read at this "true" temperature from Figure 5. The ratio of the observed specimen radiometer output to the black body output is calculated and is the emittance of the material at that temperature. If the assumed emittance is correct, the calculated value will agree with it; if not, the calculated value must be used as the former assumed value and the process repeated until the assumed emittance value agrees with the calculated value. This iterative process will converge on the correct emittance value assuming gray body distribution of most of the energy at the particular temperature. The above process was programed for analysis by a digital computer.

Error Analysis

The above procedure for determining emittance is strictly correct only for those materials which radiate as gray bodies, since the total emittance is assumed to be equal to the spectral emittance at the wavelength of the pyrometer. This approximation was used above to convert the brightness temperature to true temperature.

The error in emittance values for non-gray materials will vary depending on the difference between the 0.665 microns spectral and the total emittance, and the distribution of radiant energy within the particular spectrum. If the deviation from gray body becomes very great at temperatures up to 2500°F, it is indicated by the thermocouple measurements. On materials of low emittance, sugh as tungsten, the emittance values calculated by this procedure could be in error by as much as 20% at the highest temperatures. However, it is believed that for most materials, the accuracy is within 10%. Several things indicate that the accuracy of the emittance values is good. First, the radiometer output versus temperature curves are orderly and almost linear with only normal data scatter. Second, the data obtained on two samples of the same material are in close agreement. Third, the values of emittance for the check samples agree very well with the literature, see Figure 6.

A statistical analysis of the data accuracy is of interest. Generally, the probably error in each black-body reading is about 4%, and the probable error in each specimen reading is about 8%. If the data points are used to calculate emissivity, the maximum probable error would then be about 12%. The curve-fitting approach undoubtedly reduces this maximum to about 5%. As a general conclusion, the accuracy of the measuring system is well within the range of variation as is expecienced by different finishes on the same material, the changing chemistry of the surface at the high temperatures, surface temperature measurements, and other variables.

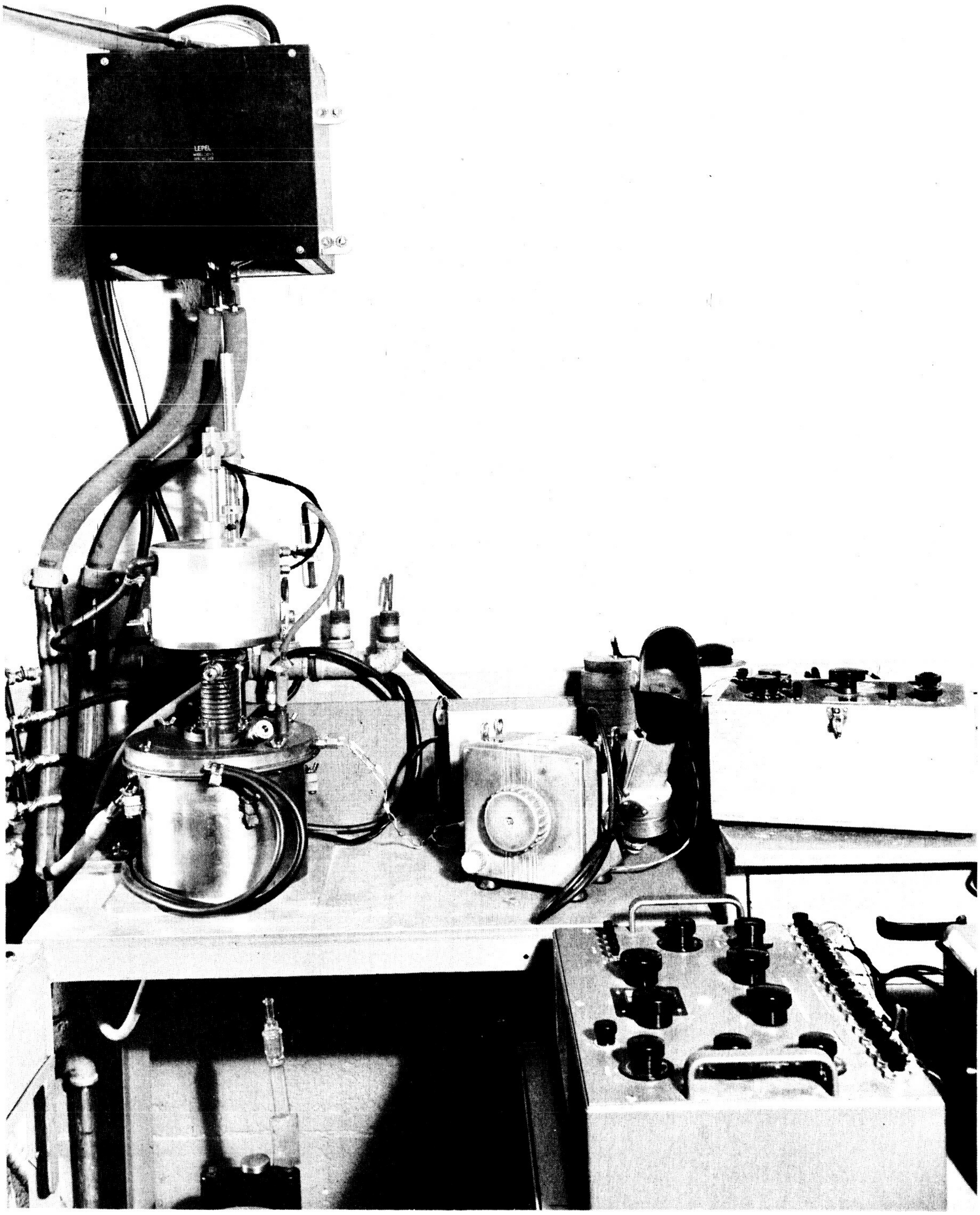
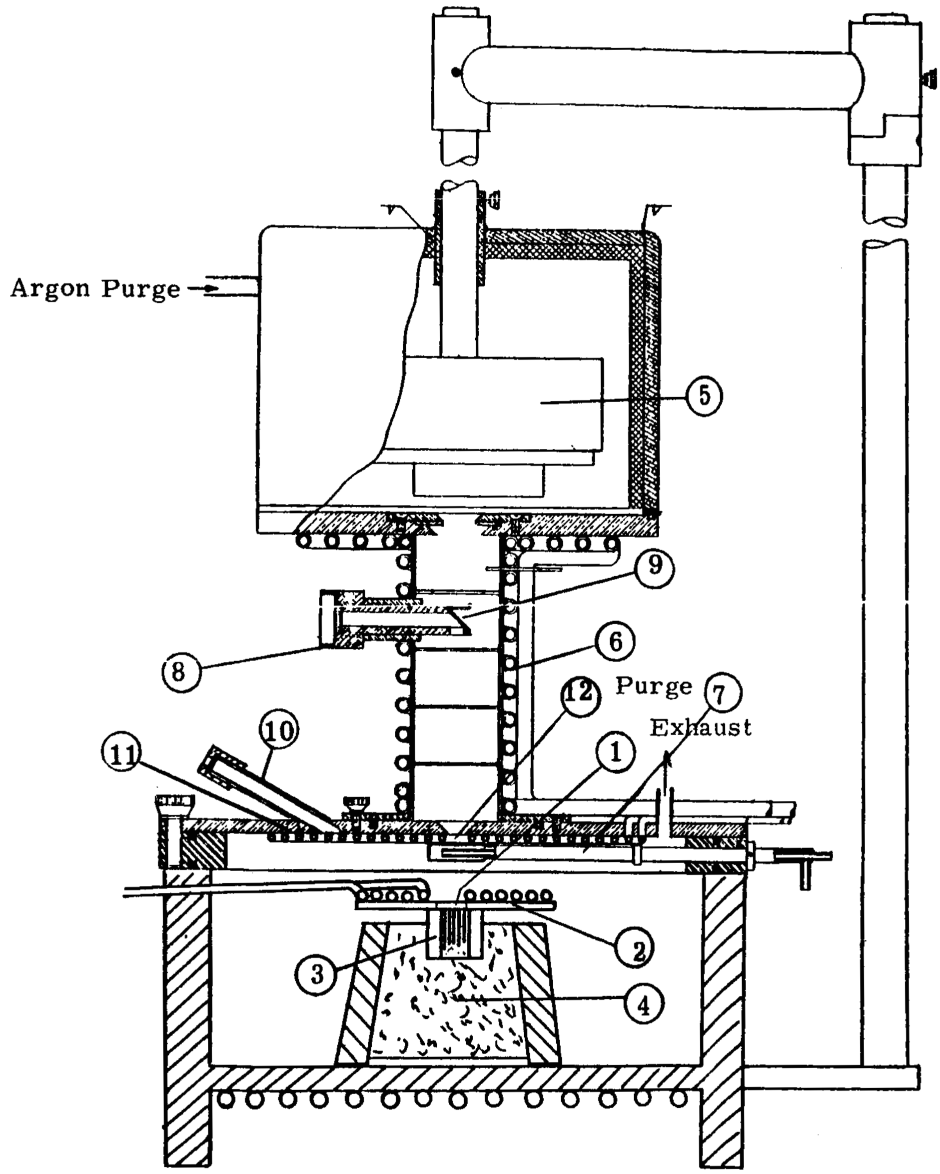


Figure 1. Picture of the Apparatus for Measuring Total Normal Emittance.



1. Specimen
2. Induction Coil
3. Zirconia Cylinder Filled with Fine Zirconia Grog and Tungsten Wire
4. Crucible Filled with Coarse Zirconia Grog
5. Radiometer
6. Water-cooled Tube
7. Blank-off Valve
8. Main Optical Port
9. Right-angle Mirror for Viewing Target Area
10. Auxiliary Optical Port
11. Cooling Coils
12. $\frac{1}{4}$" Round Stop to Limit Receiver Field

Figure 2. Cross Section of Emittance Apparatus with Flat Coil Furnace.

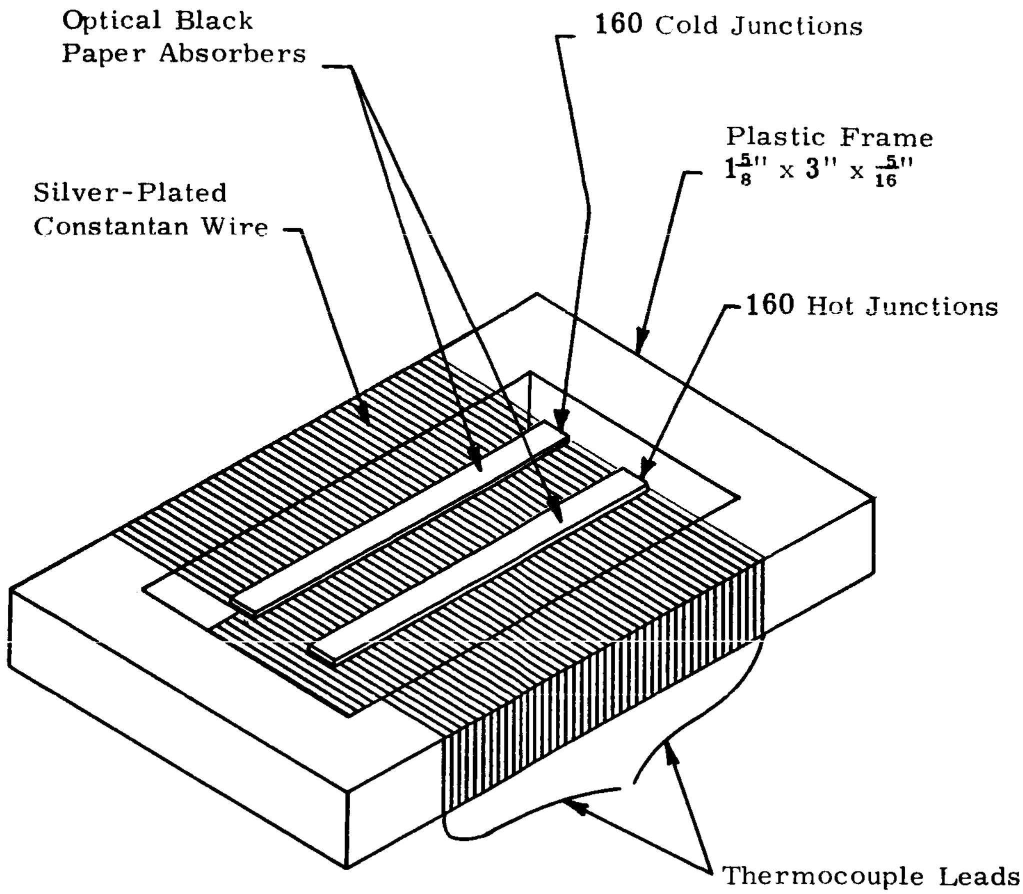


Figure 3. Schematic of 160-Junction Thermopile in Emittance Equipment.

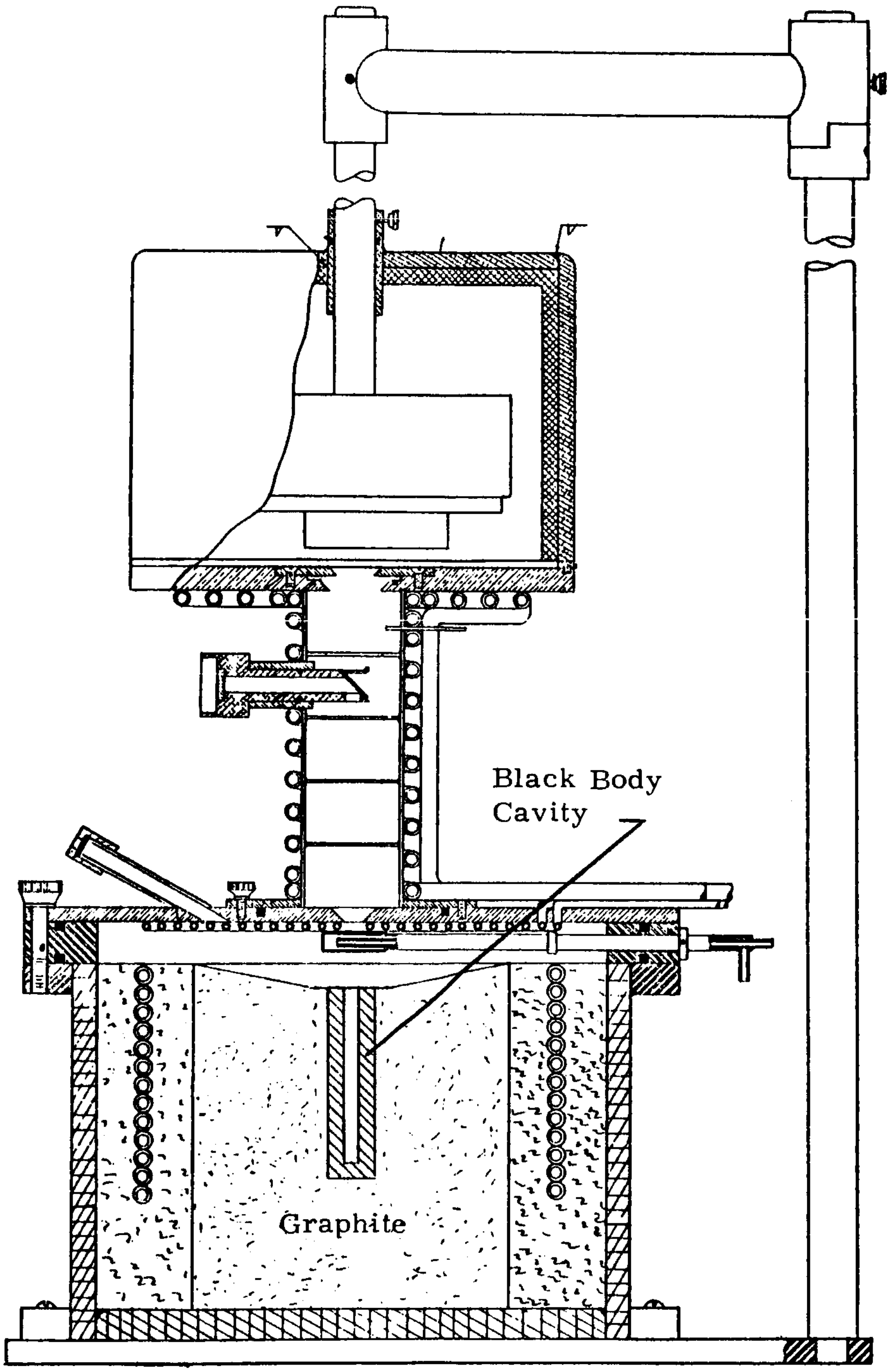


Figure 4. Cross Section of Emittance Apparatus with Black Body Furnace.

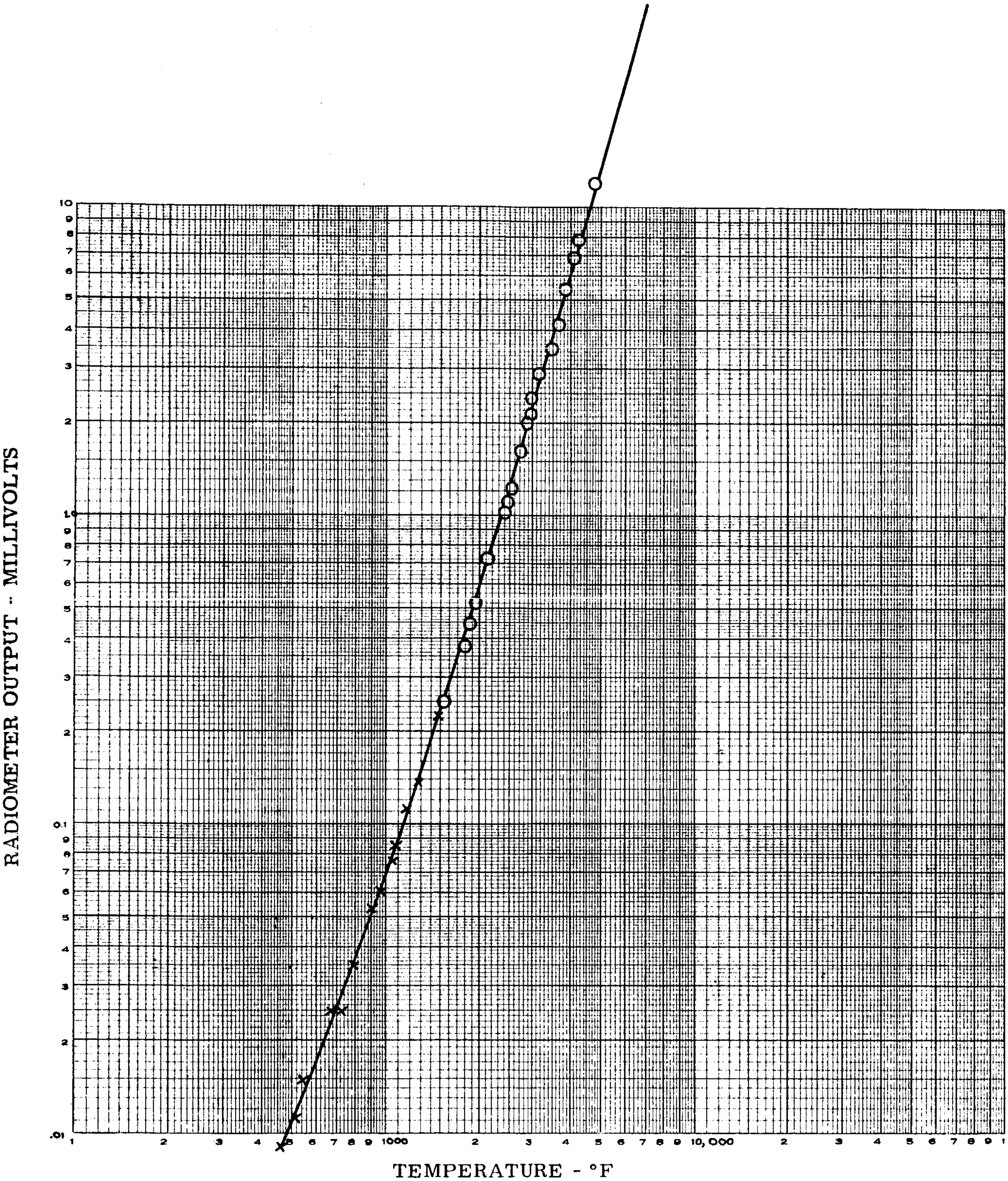


FIGURE 5. RADIOMETER OUTPUT VERSUS TEMPERATURE FOR BLACK BODY RADIATION FIGURE 6.

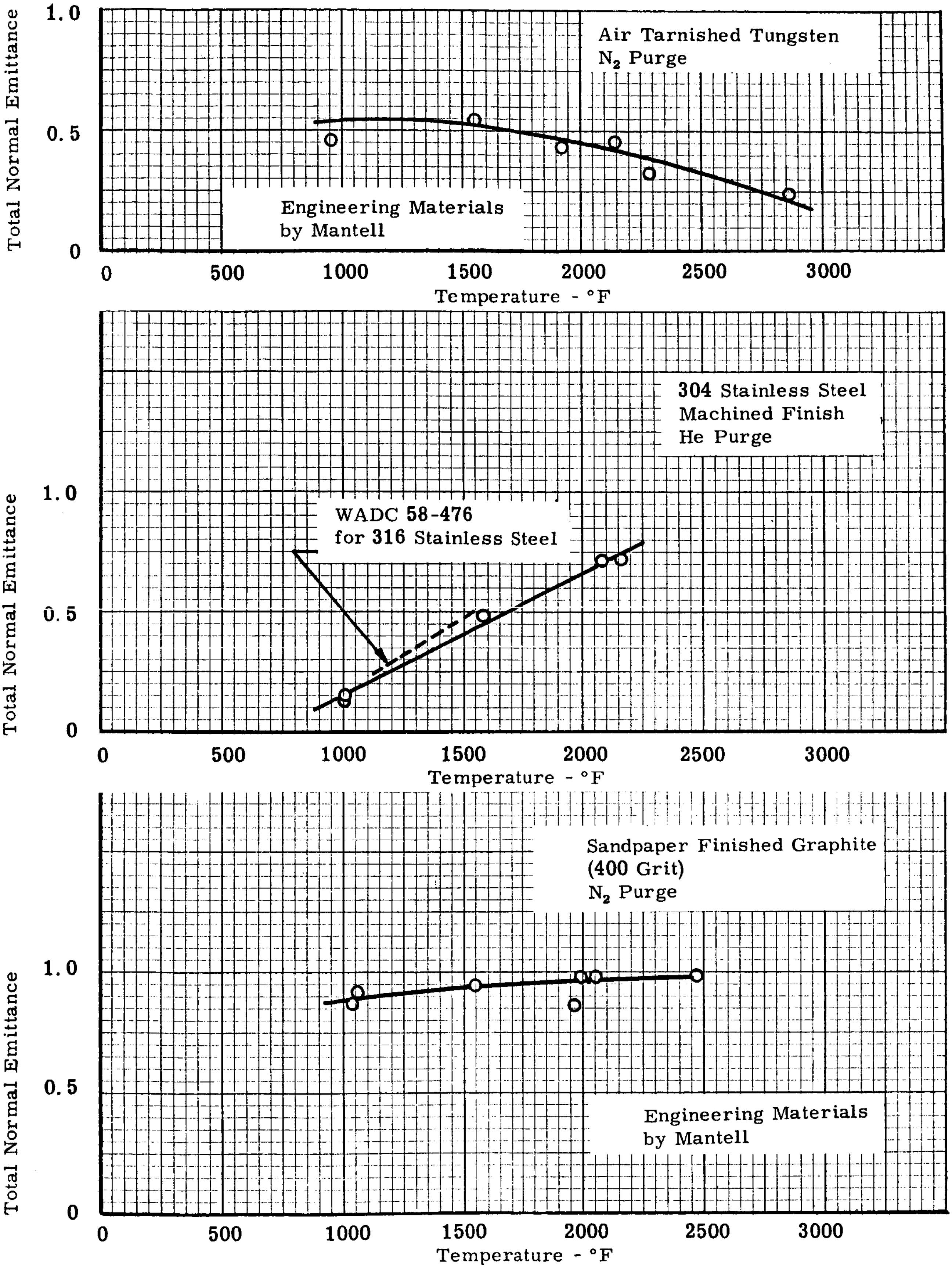


Figure 6. Calculation Standards for Total Normal Emittance.

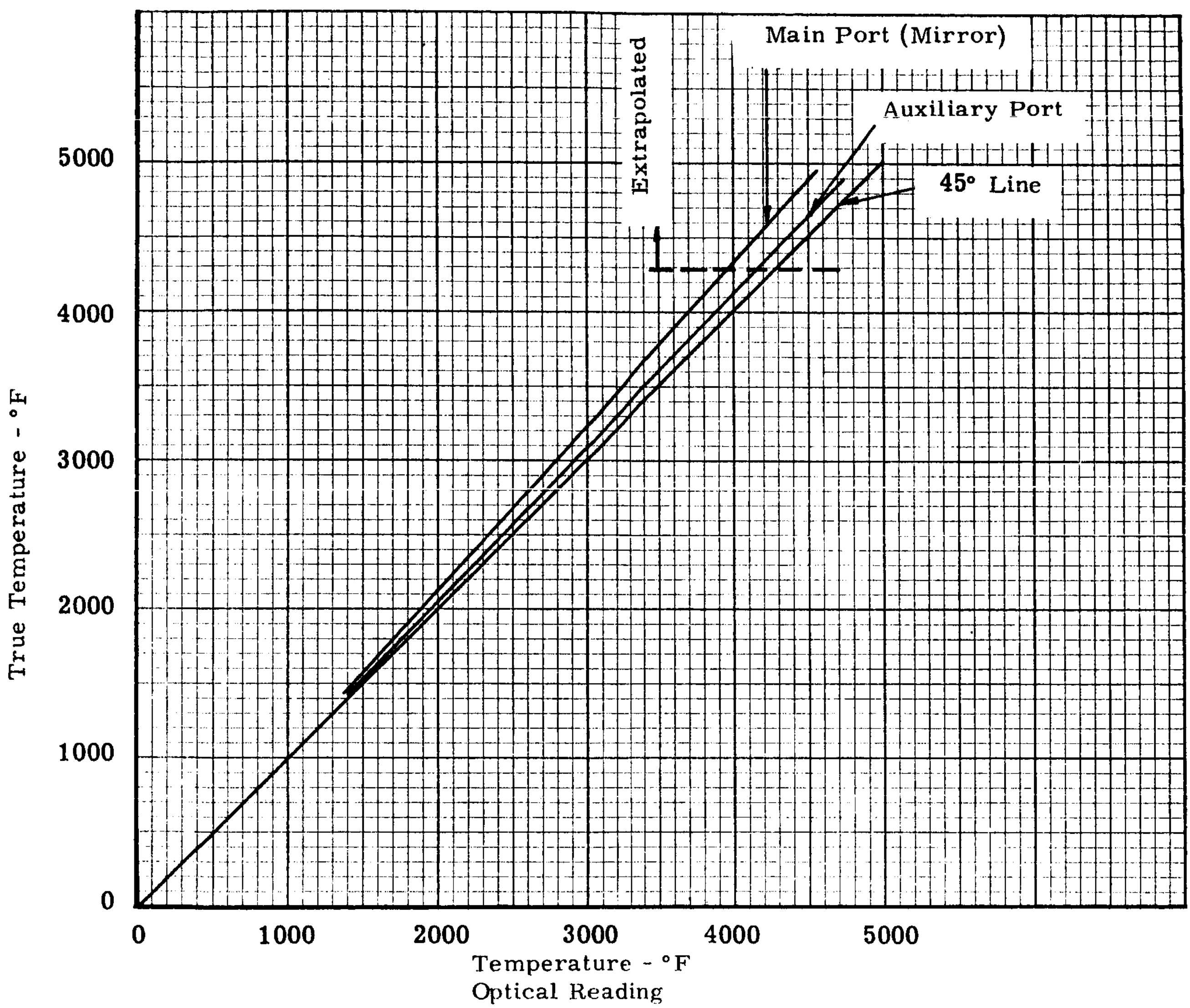


Figure 7. Correction for Mirror and Sapphire Window in Emittance Apparatus.

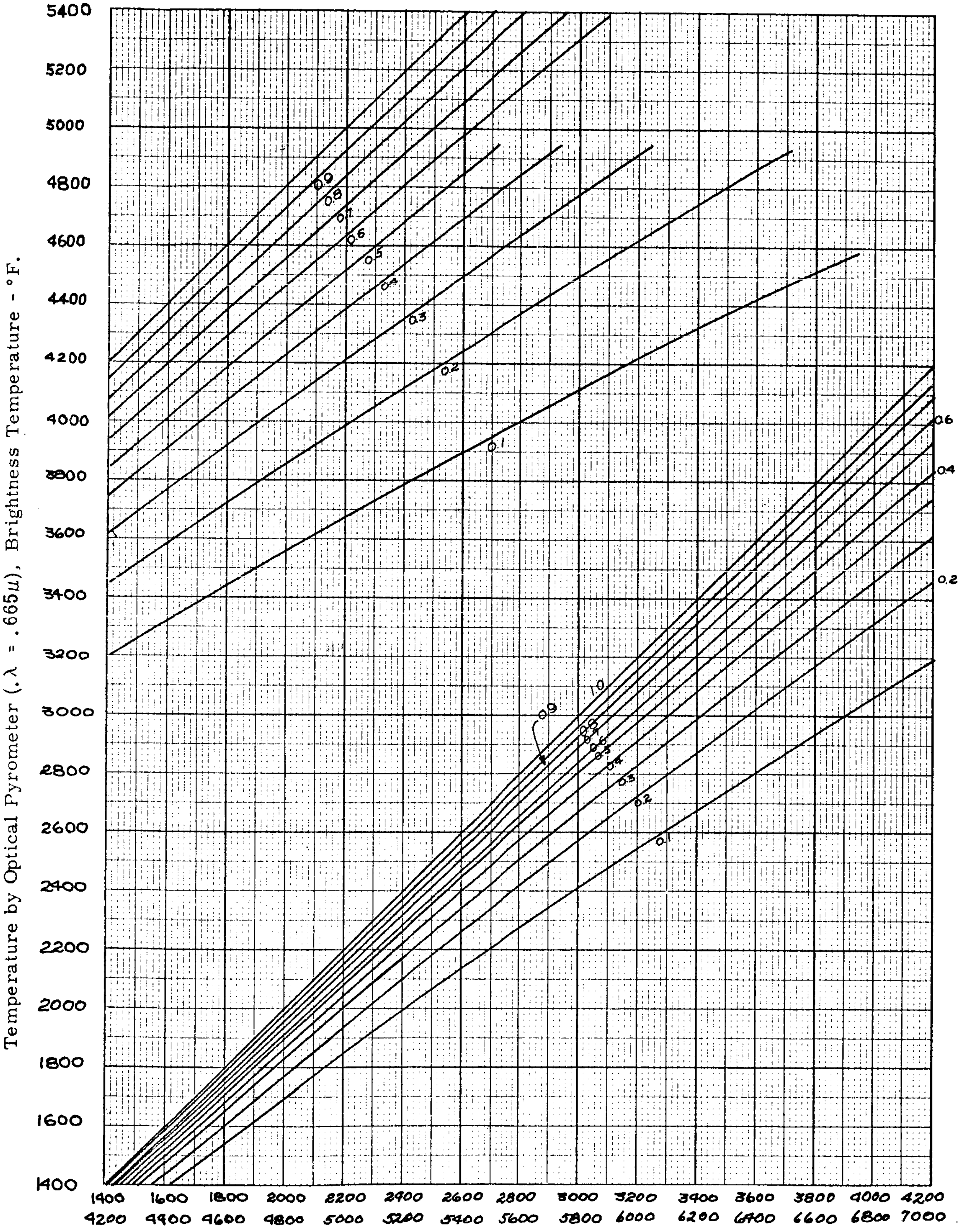


Figure 8. Correction for Brightness Temperature to True Temperature.

REFLECTANCE MEASUREMENTS AT ROOM TEMPERATURE

The method used to measure reflectivity is a direct-measurement technique, which compares the energy reflected by the specimen to that reflected by a front-surface mirror. A picture of the apparatus is shown in Figure 1.

The emission of a Globar at 1500° F is reflected off (1) the near-perfect reflector (a front-surface mirror) and (2) the specimen. The reflected intensities of the beams are measured by a commercial radiometer. The ratio of the output of the radiometer, when viewing the specimen to that when viewing the mirror, is a direct measurement of reflectivity.

To eliminate spurious reflections during the evaluation, the environment about the apparatus is kept dark and a black backdrop behind the specimen and mirror is utilized.

To obtain the emittance of a material at room temperature from the reflectivity, the following relation is utilized:

$$R = 1 - E$$

where R is the reflectivity at room temperature and E is the emittance. The above relation is valid only for opaque materials.

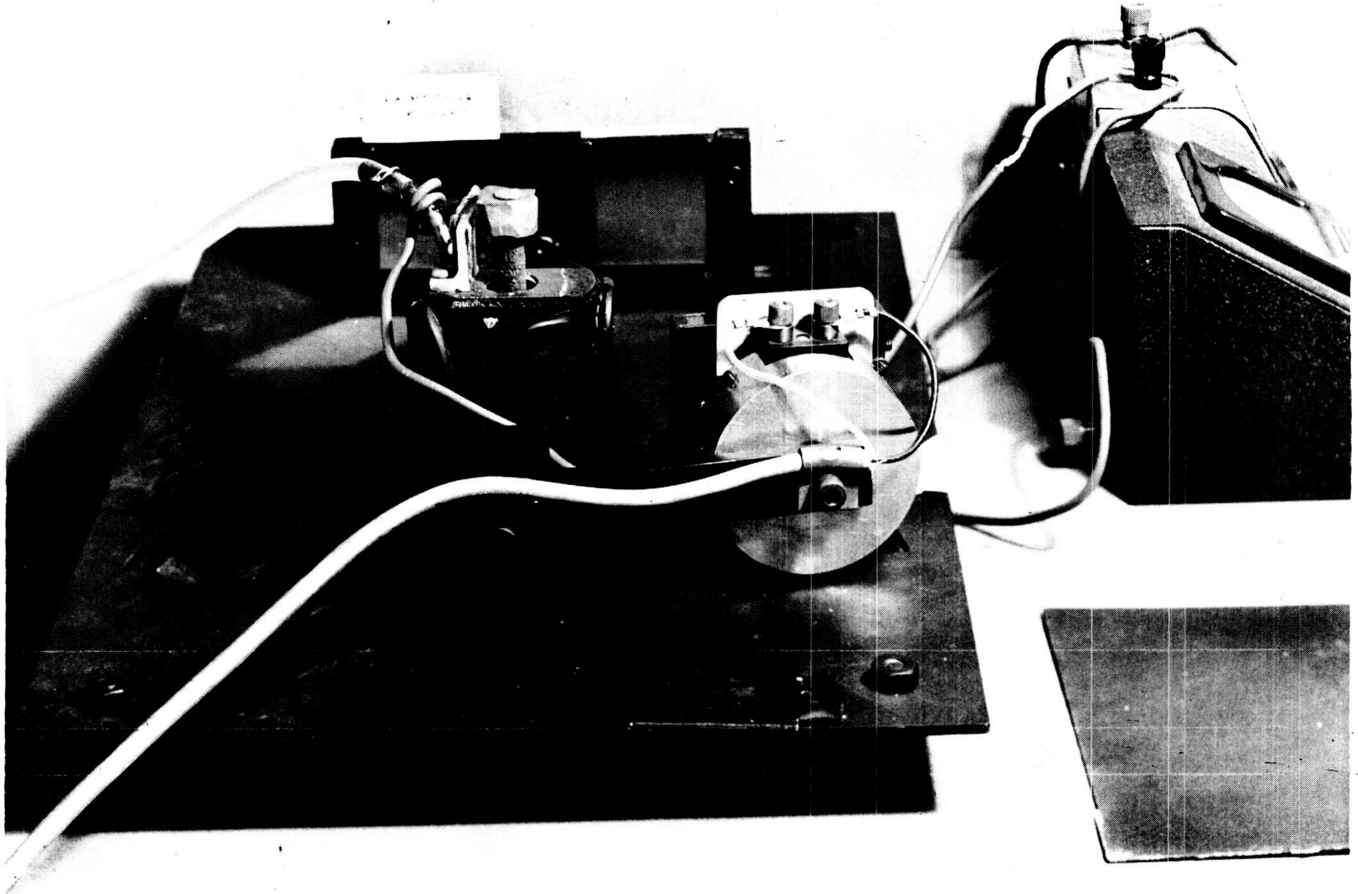


Figure 1. Picture of the Reflectance Apparatus